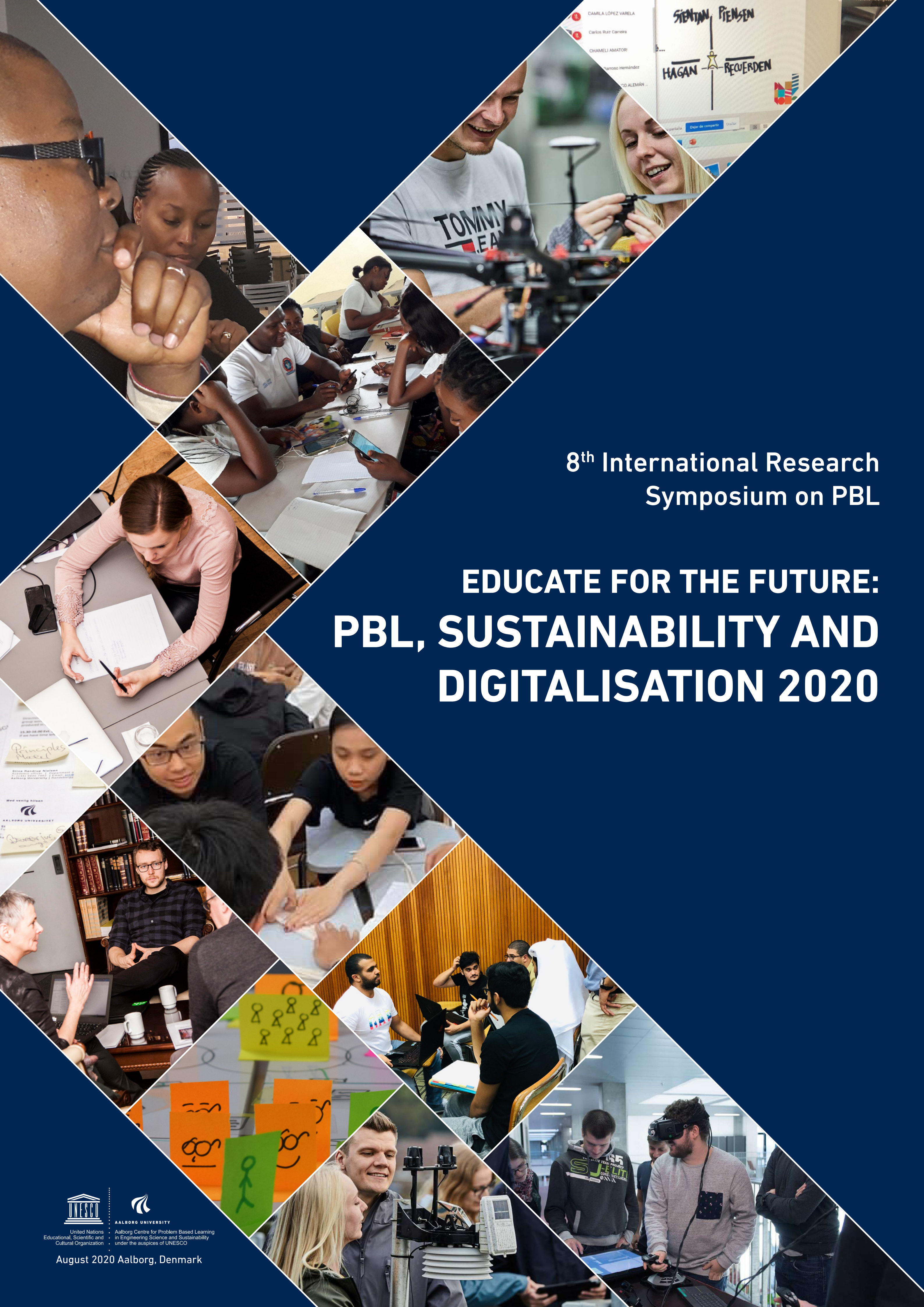
Educate for the future

PBL, Sustainability and Digitalisation 2020

Guerra, Aida; Chen, Juebei; Winther, Maiken; Kolmos, Anette



8th International Research Symposium on PBL

EDUCATE FOR THE FUTURE:
PBL, SUSTAINABILITY AND DIGITALISATION 2020

United Nations Educational, Scientific and Cultural Organization

AALBORG UNIVERSITY
Aalborg Centre for Problem Based Learning in Engineering Science and Sustainability under the auspices of UNESCO

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Edited by Aida Guerra, Juebei Chen, Maiken Winther, Anette Kolmos

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The IRSPBL 2020 proceedings are officially launch during the Kick-off seminar "PBL in a pandemic world", organised by Aalborg Centre for PBL in Engineering Science and Sustainability under the auspices of UNESCO (Denmark), in conjunction with PANPBL Association of PBL and Active Learning, PBL 2020 organizing committee and Aalborg University. This virtual event is organised after the postponement of IRSPBL 2020 and PBL 2020 conferences due to COVID-19 pandemic and international restrictions imposed to control the spread of the disease.

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Cultural Organization

AALBORG UNIVERSITY
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in Engineering Science and Sustainability
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Foreword

It is a pleasure to present the proceedings from the International Research Symposium on PBL (IRSPBL2020), organised by the Aalborg UNESCO centre for PBL in Engineering Science and Sustainability. The IRSPBL has moved around the world to Australia, the United Kingdom, Malaysia, Spain, Colombia, China, and India. Twelve years after the first symposium, IRSPBL 2020 returned home, to be organised in conjunction with the PAN-PBL annual conference, the PBL 2020. For the first time, Aalborg University would host an entire week dedicated to PBL, the Aalborg PBL Week 2020.

Right from the start, the aim of IRSPBL 2020 has been to share experience and research results on the transformation in engineering and science education to be more project-organised, and problem-based learning, i.e., PBL. The IRSPBL has created communities and networks, and the amount of best practice and research has increased enormously all over the world. The need for change has also increased during these years, from requests for engineers and scientist who are able to contribute to the solution to societal challenges, such as the Sustainable Development Goals. Therefore, competencies such as collaboration and leadership have to be learned in disciplinary contexts as well as in complex problem-solving for society.

Research has proven the value of PBL and the question is no longer if PBL works, it is now a question of which type of PBL works for which learning outcome? The variation of PBL is crucial to look into, as projects for entrepreneurship and innovation might need a type of organisation of the student learning process other than projects for understanding the theoretical foundation of a discipline. There is a variation in the use and integration of digital tools for the problem-solving process and the collaborative process. There is a variation in the educational cultures and adaptiveness for co-constructed and student-centred learning processes.

The theme chosen for IRSPBL2020/21 is, "***Educate for the future: PBL, sustainability and digitalisation***". Even though we were aware of the importance of the theme, we were far from knowing how relevant it would become in the months to come.

In the spring of 2020, the COVID-19 pandemic disrupted our work conditions and spaces, forced us into isolation and led to the cancellation of several activities, which were part of our daily (and annual) routine, such as teaching and learning activities, research, and conferences. The pandemic forced the fast creation of a "new normal" with digitalisation. For example, teaching and learning moved into virtual spaces, online, with synchronous and asynchronous activities from one day to another.

The IRSPBL 2020 was no exception and we have chosen to postpone the physical conference, and the entire PBL week, to August 2021. However, the COVID-19 pandemic also brought new opportunities for society to engage and remain connected. Therefore, we have organised a series of online events in the advent of PBL week 2021. We start with a kick-off seminar, entitled ***"PBL in a pandemic world***", on 18 August 2020**.** The seminar is organised in conjunction with the PBL 2020 organising committee and the PAN-PBL society.

In autumn 2020, a series of virtual webinars under the theme "***Flipped IRSPBL 2020-21: moving towards a virtual PBL community***" will take place, starting on 28 October. Here, we invite the authors to present their contributions, and the entire society to engage in new ways and spaces to share knowledge, discuss perspectives, and reflect on how PBL can educate for the challenges and uncertainties posed by the future.

The IRSPBL 2020 has collected 51 contributions from 26 different countries, all compiled in this book. The contributions cover a number of relevant topics: variation and understanding of problems and projects; implementation of new methods and programs (BIM); blended PBL learning environments; generating innovative and interdisciplinary knowledge and practice; implementation of PBL around the world; PBL, industry and entrepreneurship; development and awareness of future competencies and learning spaces, and assessment and the teachers' role.

This book represents some of the newest results from research on PBL and best practice to inspire other practitioners to innovate their teaching and learning activities. We hope that you will find the book useful and inspirational for your further work.

The editors:
Aida Guerra,
Juebei Chen,
Maiken Winther,
Anette Kolmos

Educate for the Future: PBL, Sustainability and Digitalisation 2020
Edited by Aida GUERRA, Juebei CHEN, Maiken WINTHER and Anette KOLMOS

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Blended PBL Enviroments

Tech students' perceptions of social media's usefulness during PBL group work

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Abstract

This study explores tech students' perceptions of social media's usefulness during PBL group work. In contrast to much of the previous work, this study is not focused on effects; instead, it is aimed at determining the extent to which students perceived various social media platforms as useful within the context of their PBL group work. This study is based on 15 groups (45 tech students) enrolled at Aalborg University and uses the principles of problem-based learning. The study's procedures included a semi- structured interview guide and a card sorting method. All participants in this study used social media for group coordination. Messenger, Skype, WhatsApp, Snapchat, and Facebook were all used in dynamic, changeable, and different ways within groups for coordination. Moreover, if social media platforms were used for non-academic purposes, they were mostly perceived as not useful and distracting. However, if the social media platforms were perceived as useful, they tended to contain group- and project-relevant content. The various social media platforms were perceived differently and used for different purposes throughout the PBL stages, depending on the individuals, and their use was not persistent or variable due to positive, neutral or negative perceptions. It can also be concluded that real-time synchronous and collaborative platforms are important for facilitating students' group work and projects. In addition, the students perceived that a strongly focused group with good group dynamics benefits more from using social media than does a more unfocused group with an excessively friendly attitude.

Keywords: Social media, PBL group work, Tech students, Card sorting, Friendship pairs.

Type of contribution: PBL research

1 Introduction

It is well-known that students use social media platforms inside and outside the university context (Lau, 2017) and that such platforms are used inside and outside of PBL group work (Fonteijn & Dolmans, 2019; Ryberg, 2019). However, previous studies reported considerably divergent findings regarding the usefulness of social media within the PBL group work context, including positive, neutral and negative effects (Cheston, Flickinger & Chisolm, 2013; Lau, 2017). From a theoretical and methodological perspective, these divergent findings regarding social media use in PBL group work, including the difficulties of evaluating the effects, are quite interesting. Some reasons for the complexity of evaluating social media's effects on PBL group work might be found in the many variables present in the users, contexts, and technology, as well as the rather complex perceptions, behaviors, and interactions between them. In previous studies, researchers mentioned some of the many variables' limitations (Lau, 2017; Lou et al., 1996; Ryberg, 2019). Some variables that could be considered within the context of evaluating social media's effects on PBL group work include e.g.: country, the university and its location(s), students' ages, gender, semester, cultures, languages, student diversity, study programs, fields of study, and PBL philosophies. Furthermore, the participants' individual motivations, presence, mental state, expectations, social skills, social relations, and involvement all differed in terms of learning and social media use. Given so many variables, it is very difficult to conduct comparative studies and provide generalized findings.

This study's background supplements the numerous previous studies aimed at investigating students' social media use in the PBL group work context. However, this study avoids the complex effect evaluation and instead evaluates the complexity of students' perceptions of various social media platforms' usefulness to their PBL group work. The study's research question is "What are tech students' perceptions of social media's usefulness within the PBL group work context?" In this study, tech students are defined as students enrolled in programs within the Technical Faculty of IT and Design at Aalborg University in Denmark. Almost all study programs at Aalborg University use the principles of the Aalborg PBL model (Barge, 2010; Kolmos, Bøgelund & Spliid, 2019). The tech students must complete group projects every semester in collaborative teams of two to seven students. The projects are assessed and account for half of the students' European Credit Transfer and Accumulation System (ECTS) points. From a philosophical and sociological standpoint, Aalborg University's PBL method also implies that the projects are unique, address real-life problems, involve new and complex tasks or problems, and extend beyond traditional organizations and knowledge (Barge, 2010; Kolmos, Bøgelund & Spliid, 2019).

Perceived usefulness is defined as the degree to which the students believe that utilizing social media platforms will improve their work performance, which is similar to how Davis (1989) defined usefulness within the technology acceptance model (TAM). The TAM approach was previously applied to confirm the acceptance and use of various information systems, including PBL and educational contexts (Bazelais, Doleck & Lemay; Park, 2009). Perceived usefulness is a complex construct, so it might not be possible to measure it directly; instead, researchers must rely mainly on inference. Perceived usefulness comprises affective (feelings), cognitive (beliefs), and behavioral (actual) actions. This is similar to how Baron and Byrne (1984) described attitudes toward specific persons, ideas, objects, or groups.

A social media platform is defined as an interactive software platform that facilitates the creation and exchange of user-generated content and for which users must create service-specific profiles and identities (Kaplan & Haenlein, 2010; Obar & Wildman, 2015). Furthermore, social media platforms are characterized by the development of online social networks by connecting a user's profile with the profiles of other individuals and groups (Obar & Wildman, 2015). This definition of social media encompasses a large suite of software, including messaging, video and photo sharing (e.g., Twitter, Snapchat, Instagram, Slack, Discord, Facebook, WhatsApp, Messenger, YouTube, Skype, and e-mails), forum, discussion board and blogging (e.g., reddit, LinkedIn, and Facebook), and management software (e.g., Trello, Asana, Google Drive, and Overleaf). This definition and typology is also similar to previous studies' approaches of social media (Lau, 2017; Obar & Wildman, 2015; Ryberg 2019).

2 Previous work

In some studies, social media platforms have been found to support interaction and synergy between personal and collective knowledge, including content generation (Ryberg, 2019). Through this supportive facilitation, social media platforms create new knowledge and support innovation within teams and PBL groups (McLoughlin & Lee, 2010; Razmerita & Kirchner, 2014; Ryberg, 2019). A large number of previous studies found that social media can support offline engagement inside and outside the university context and had positive effects on factors such as integration, extracurricular activities, student retention, university communities, and student groups (Barnes, 2017; Gray, Chang & Kennedy, 2010; Heriberger & Harper 2008; Junco, 2012). Another positive effect of social media is found within PBL resource management, which includes storing, sharing, and annotating references, bookmarks, documents, and pictures (Bacon & Mujkic, 2016; Ryberg, 2019). Within academic and cocurricular discussions, social media has been found to have positive effects on grades and has led to higher levels of engagement (Junco, Heiberger, & Loken, 2011).

Researchers have also found that social media has negative effects, and does not facilitate offline interactions with peers (Berger & Wild, 2016). Furthermore, studies have shown that overinvolvement or hyperbonding through social media has adverse effects on academic performance (Al-Menayes, 2014; Junco & Cotton, 2012). Several studies' (Ravizza, Hambrick & Fenn, 2014; Junco & Cotton, 2012; Lau, 2017) results indicated that social media multitasking for nonacademic purposes while working correlates strongly with negative academic performance. Studies have also highlighted that social media can have highly addictive qualities that can result in non-productive student behaviors such as group absenteeism, sharing old exams and summaries via social media, or off-task behavior, resulting in peer groups that disrupt learning (Fonteijn & Dolmans, 2019). Some studies have also reported neither positive nor negative effects from social media use for academic purposes (Lau, 2017; Sendurur, Sendurur & Yilmaz, 2015).

3 Methods

The sampling method used was convenience sampling within the target group of tech students at Aalborg University's Copenhagen campus. The sampling took place in two rounds: April-May 2019 and November-December 2019. During both periods, students were close to completing their semester projects. This study was based on 45 tech students (38 male and 7 female) enrolled in PBL groups across various bachelor's degree programs. The 45 tech students were sampled from 15 groups of 4-6 students. Using friendship pairs (Bjørner, 2015a), each of the 15 groups selected three students to participate in study. The first data collection period included two groups from the ITCOM program and three from the medialogy program. All groups comprise fourth-semester bachelor's degree students. During the second data collection period, we sampled 10 groups of third- and fifth-semester bachelor's degree students. These included 6 medialogy groups, 2 sustainable biotechnology groups, and two manufacturing and operation engineering groups.

We provided all participants with anonymized ID numbers, and this study required no personal information. We applied special ethical considerations for this study in accordance with the ICC/ESOMAR International Code (ESOMAR, 2016) and used a specific checklist from the university for research-related data processing. Legal access, permission, and consent were made. We applied very special considerations when recruiting students for this study, such as ensuring that recruitment was not performed by a researcher whom the students knew and that the students were not enrolled in one of the researcher's courses. This ensured that they were not unduly pressured to cooperate with the research request. The informed consent form included a description of the study's aim and instructions for completing the study. In addition, it highlighted the right to withdraw at any time, as well as the right to refuse to answer the questions. We were very aware that interviewing students about their social media use within a group work context might bring up sensitive topics and potentially expose their emotions (Dickson-Swift, 2017; Lee, 1993) and PBL group work conflicts. Therefore, we considered it rather important to create a relaxed atmosphere in which the researchers and participants felt at ease (Lee, 1993). We ensured a high level of integrity, respect, and empathy while remaining professional.

3.1 Procedure

The procedure for all 15 groups of 3 students followed a semi-structured interview guide, and all interviews were performed using the friendship pairs method (Bjørner, 2015a). The friendship pairs method is a variation of the in-depth interview in which two to three participants who know each other well (family members are excluded) are interviewed together. Friendship pairs can provide advantages because they enable participants to feel more comfortable, thus facilitating a more open, spontaneous, and deep discussion (Bayley & Nancarrow, 1998). We used this method because it enabled participants to confer with one another and agree or disagree.

The semi-structured interview guide was divided into themes using five overall questions: 1. What do you consider the main strengths of the AAU PBL model? 2. What do you consider the challenges of group work? 3. How do you coordinate work in your group? What happens if not everybody is present? 4. What are the main distractions that emerge? 5. What can you say about the use of social media in your group?

Card sorting was performed using a coordinate system. The vertical axis had extremes labeled “Not Useful” and “Useful,” and the horizontal axis has extremes labeled “Not Distracting” and “Distracting.” The participants were then presented with cards or Post-it notes on which the researchers had written the names of various common social media platforms. The participants could also write their own social media platforms. The participants were then asked to arrange the various platforms using the coordinate system.

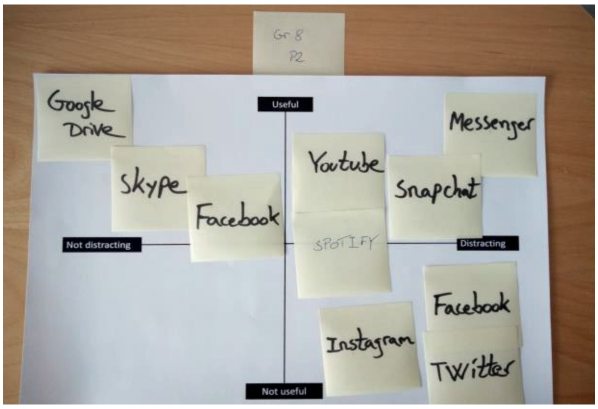

Figure 1: Example of participant arranging various social media platforms using the coordinate system

The card sorting method was used to provide more specific and in-depth interviews about social media by going from a potentially abstract level to more specific use. Within the coordinate system, the card sorting method was also used to identify the tech students’ perceptions of the social media platforms’ usefulness within the context of their PBL group work. During the card-sorting session, the participants were asked to elaborate on their card arrangements to facilitate further insightful discussion based on their thoughts.

3.2 Data analysis

The interviews were analyzed using traditional coding (Bjørner, 2015b) and content analysis. The interview data analysis followed four steps: organizing, recognizing, coding, and interpretation. The first step was to organize and prepare the data for analysis. The interviews were transcribed verbatim, and the visual materials (sorted cards) were catalogued. The next step was recognizing; transcripts were read several times by two researchers to establish the concepts and themes. This second step provided a general sense of the information and an opportunity to reflect on its overall meaning. The third step was coding, during which the researchers organized and assigned the data to categories and subcategories. The last step was interpretation, which included Creswell’s (2014) question “What lessons have we learned?” as well as considerations of how students perceived the usefulness of social media within the PBL group work context

4 Findings

4.1 General perceptions of the PBL model and group work

There were various perceptions of the Aalborg PBL model and group work. However, most participants had positive attitudes and experiences. Some students mentioned the social and work-related aspects of the PBL model. In addition, the PBL model was perceived as helping students both better integrate into the study environment and prepare for future jobs in the labor market. The negative perceptions were mainly related to the specific group work. Several students mentioned that the project work could be very mentally demanding and time consuming and that working in a group of 4-6 people required many social skills and competencies. The majority of students recognized some pressure from the group work project. However, the majority also perceived this pressure as a motivation to study. It is interesting that the students were quite aware of the project's process and synthesis. The participants perceived pressure and an inherent requirement to be less distracted when approaching the project's due date. This also appeared to correlate with their social media use.

> *The distractions from social media go along with the project process. We tend to be much more distracted in the beginning—for example, when finding our problem—and when doing state-of-the-art research. We are more focused closer to deadline... I guess this also has something to do with the group's culture and what is expected and accepted. (ID34, Group 12)….Yes, which actually also caused some major conflict in our groups regarding how much we use social media and become distracted from the real project work, especially toward the end. (ID36, Group 13)*

In general, the students perceived considerable distractions from social media, and they wasted a great deal of time, but it is also interesting that this was considered part of group conflict and work culture management, as expressed by ID34 and ID36. It is also interesting that almost all groups mentioned the correlation of useful and non-distracting social media use with the importance of having a strongly focused group, strong leadership, and good group dynamics. In contrast, most groups also mentioned examples of and experiences with unfocused groups with excessively friendly attitudes, which led to more distracting use ofsocial media.

> *When we don't have such a leader, people are pretty passive… (ID3, Group 1)*

> *Due to good group culture…when we get together, we are also more focused. (ID5 group 2)*

> *Someone in the group needs to set the standard and be the group leader. If this fails, we spend more time on playing games and other things we actually shouldn't do when getting together for group work. (ID22, Group 8)…Yes, I have tried this previously. The problem is also if the group's attitude is too friendly. We should, in general, be more focused when we are here and watch stupid videos or get on Steam when we are at home. (ID24, Group 8)*

> *If we spend less time on crap on social media here in the group room, we can avoid stress in the end. We could actually also go home earlier and get more leisure time….I don't know why we always end up spending so much time on Facebook and especially games.* (ID37, Group 13)

4.2 Social media's perceived usefulness

Based on the card sorting activity (Table 2), the participants arranged various social media platforms using the coordinate system. The numbers indicate how many individual students selected the specific card, and the bubbles' sizes represent these numbers. Students could choose to place the same social media platform in multiple locations using the coordinate system. The placement of the given platforms is a synthesis of their general placement, which ranged from highly useful to not useful at all on the horizontal axis and from very distracting to not at all distracting on the vertical axis.

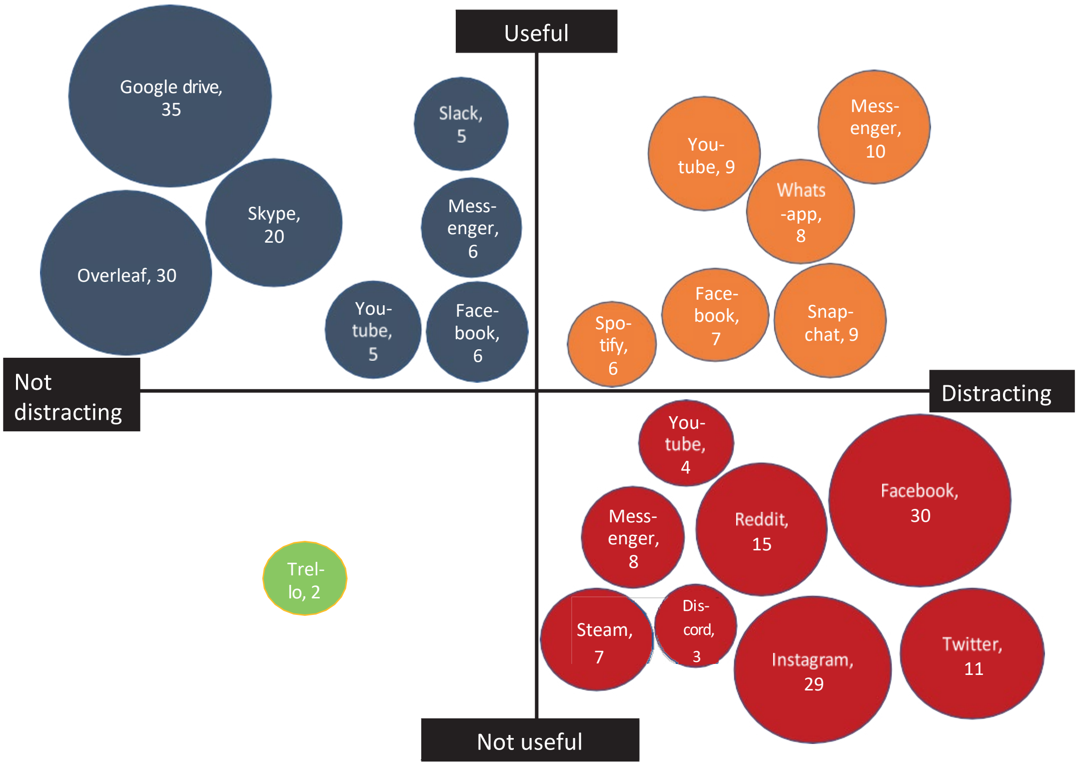

Figure 2: Aggregated social media positions within the coordinate system; n=45.

Most students positioned Google Drive (35 students) and Overleaf (30 students) in the upper left corner because they considered these platforms both useful and not distracting. In the interviews, students perceived these platforms as quite productive when used for group work. Google Drive and Overleaf might not be perceived as the most common or typical social media platforms, but they are interactive software platforms with specific associated profiles that enable students to create and exchange user-generated project content. The participants elaborated that they use Google Drive and Overleaf to leave comments for other group members and share documents, and that these platforms are not distracting because they involve only project-relevant content.

> *I think Overleaf is good for giving feedback to each other, to see if something is missing or a reference…then you can leave a comment. (ID5, Group 2)*
>
> *Google Drive and Overleaf are good and not distracting, as they only cover project-relevant things. (ID16, Group 6)*
>
> *We use Google Drive not only as shared storage space for our various files and work-in-progress papers, but also to produce, use, and comment on files simultaneously (ID29, Group 10)…. In group work, it is pretty smart to access files, write in them, and comment on them at same time. (ID30, Group 10)*

Google Drive was perceived more useful than Overleaf. Google Drive offers different features for internal collaboration and is perceived as a good shared folder manager, whereas Overleaf is perceived as a “Power tool that makes the project possible, enables us to print the project” (ID3, Group 1), and “helps us get a good overview of the project" (ID5, Group 2). It is also interesting that Skype, similar to Google Drive and Overleaf, is perceived as useful and not distracting. Skype is used when holding meetings and coordinating to include students who cannot be physically present. It is also used to share links.

> *Skype is very useful if you're sick and have to be at the group meeting. (ID6, Group 2)*

> *We use Skype during our group meetings to share and send links, including Google docs links. It's faster than e-mail, and everybody in the group can follow instantly. (ID17, Group 6)*

However, some students perceived Overleaf as a bit more difficult to use, less user friendly, and requiring a "programmer's brain" (ID14, Group 5). Some students mentioned that they lacked technical support and better overviews of social media platforms for managing their project work, as well as common standards for project writing, on the platforms they used.

> *I know that some groups are using Asana as a project management tool, and they have spoken about it very positively. I don't know the details, but in general, we lack a better overview and sometimes also help using Overleaf. (ID33, Group 11)*

> *We are left a bit alone regarding how to use social media platforms in a good, academic way. The supervisors must have some experience from their own projects. (ID22, Group 8)*

Thirty students perceived and positioned Facebook as both distracting and not useful. However, they provided mixed elaborations on this position. Seven students considered Facebook useful and distracting, but 6 students labeled it useful and not distracting. Facebook was perceived as the primary group coordination platform by 10 out of 15 groups. There seemed to be some omnipresent coordination habits regarding the use of Facebook, and there were both positive and negative perceptions of Facebook use within the group work context.

> *Facebook, for us, is used for messaging…it could be substituted, and we could use Slack instead… but because of the network effect, I signed up for Facebook. (ID3, Group 1)*

Even though Facebook was the most used platform for group coordination, the participants were also very conscious of the distractions that Facebook might cause because it contains a great deal of non-project-specific content. One participant (ID3, Group 1) had a browser extension that blocked Facebook from his PC. Another regarded Facebook as "an awful time killer that I'm addicted to" (ID1, Group 1).

> *Facebook works because everybody uses it. (ID40, Group 14)*

> *There are also events at Aalborg University that posted on Facebook. It is the main source for these events. (ID4, Group 2)*

> *The university also uses Facebook for communication. It is distracting because the content is not group- and project-relevant. However, the content is also useful. There is also student-relevant information on Facebook, but of course, there is also lots of other very useless content…. Maybe the university should use Moodle or other channels for communication. (ID26, Group 9)*

All 15 groups used social media for group coordination. Messenger, WhatsApp, Snapchat, and Facebook were used in very dynamic and different ways within the groups. All social media platforms were perceived as useful if they contained group- and project-relevant content. However, if the content lay outside the academic context, it was perceived as not useful and distracting. Some students perceived Snapchat as a useful platform for quick communication management and sending reminders to other members. Interestingly, Snapchat was used in some groups to emotionally support group members using emotional snaps. Twitter in general was perceived only as a distracting platform that was not useful, even though Twitter could be used for group coordination and communication like Messenger, WhatsApp, Snapchat, and Facebook. However, among this study's participants, very few used Twitter for academic or group management purposes. Discord, Steam, and Instagram were also perceived as not useful and distracting, and several participants used the same wording as “there is no project-relevant use” (ID13, ID14, Group 5; ID22, Group 8; ID33, Group 11).

YouTube, like Facebook and Messenger, was perceived differently among the students. Nine students perceived YouTube as useful and distracting, and five students perceived it as useful and not distracting.

> *YouTube is actually a very good platform for ideas, especially for how to do things with statistics, programming, rendering videos, etc. (ID25, Group 9)…True, and it is sometimes also used for TED talks and other relevant stuff. (ID26, Group 9)*
>
> *YouTube can be good for ideas and introducing some content, but there are also lots of irrelevant videos, which makes YouTube rather distracting as well. (ID41, Group 14)*

Some students used Spotify to focus on work and used headphones to avoid disturbing other group members. However, students also stated that loud volume could sometimes affect others’ work performance. Students could choose pre-determined cards and write their own. Steam, Discord, Trello, Slack, and Spotify were listed by the participants. However, it is interesting that others, such as Moodle and Dropbox, were absent.

5 Conclusion

Previous studies identified the benefits of social media within the PBL group work context, the strongest of which include the following: a better perception of group work, support for offline engagement, interaction support, group synergy and content generation support, improved knowledge exchange, and group and resource management facilitation. However, social media platforms were also reported to have negative consequences such as distraction, negative group performance, non-productive student behavior, obsession over one’s self image, and negative correlation with academic performance.

All participants in this study used social media platforms for group coordination. Messenger, Skype, WhatsApp, Snapchat, and Facebook were all used in rather dynamic, changeable, and different ways within the groups. As in other studies (Ravizza, Hambrick & Fenn, 2014; Junco & Cotton, 2012; Lau, 2017), we found that if a social media platform was used for non-academic purposes and contains non-project- relevant content, it was perceived as not useful and distracting. However, social media platforms were perceived as useful if they contained group- and project-relevant content. We also found that the students perceived that having a strongly focused group with good group dynamics led to more benefits from using social media than did a more unfocused group with an excessively friendly attitude.

Based on this study’s results, various social media platforms are perceived to have different purposes at different PBL stages, depending on individual use, and their use was not persistent or variable due to positive, neutral or negative perceptions. In addition, real-time synchronous and collaborative platforms are important to supporting students’ group work and project facilitation. Google Drive, Overleaf, and Skype are perceived as useful and not distracting. They are part of the PBL learning synthesis process and function mainly as project writing and management platforms.

The findings from this study can serve as a reminder that today’s students have grown up with social media multitasking. With a balanced facilitation, social media within PBL group work can be adopted to improve group collaboration. Furthermore, our findings also highlight that social media can be used to motivate students to learn and reinforce project materials, including literature and selected content for student supervision. However, for both ethical and didactic reasons, differentiated access is needed, separating students’ internal communication and work and the academic teachers’ access for e.g. student supervision.

In this study, we find the structured qualitative card sorting is a good method for encouraging participants to talk about the rather abstract topic of the usefulness of social media within the context of their PBL group work. However, we recognize a limitation of this study is based on our only qualitative approach with participants enrolled in few bachelor's programs. In future studies, researchers can use the card sorting method with more participants for a longer period of time. To increase the validity and provide a more comprehensive data foundation, this study can be supplemented with a quantitative approach to gain knowledge of what and how many types of social media each student has used, as well as their social media time spent within specific PBL tasks. Observations of the actual social media usage during group work may also be of interest. However, within the observational approach there is some additional ethical concerns and potential participant bias that would need to be addressed.

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Research on the online PBL education system using AI

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Abstract

The importance of problem-based learning and project-based learning (both abbreviated to PBL) which tackle complicated problems is perceived in engineering education and in addressing the Sustainable Development Goals (SDGs). Kanazawa Institute of Technology (KIT) applies PBL to its design and engineering program as Project Design (PD) Program to grow up independently minded, actively engaged engineers. Although many universities perform PBL in regular curriculum education, PBL contents depend on the teachers' know-how or their individual guidance.

To advance an educational reform, introduction of the online education system is promoted. In recent years, the classes based on lectures can be taken on-line. MOOC (Massive Open Online Courses) has spread all over the world. More than ten million learners use Cousera® or edX®. Other than MOOC, the flipped learning with e-learning or e-Syllabus is carried out widely using PC. Furthermore, the trial which uses AI (Artificial Intelligence) and Chatbot for education is studied.

How can the combination of PBL and digitalization realize the online PBL education? Based on the rich instructional materials, students' deliverables and questionnaire results of KIT PBL courses, the authors are investigating the online PBL education system which uses AI instead of teachers' direct instruction. At first the system survey focused on digitalized design platform which students can use together to design online. There are several web-based design platforms available. These tools may be useful when the design objects are clear. However, we have noticed that more common communication tools are effective for our PD Program. There are many free communication and collaboration tools: students use SNS more than e-mail. We propose the on-line PBL education system using Slack and Chatbots. Since the system is still a development phase, we introduce the outline and feature.

Keywords: PBL, AI (Artificial Intelligence), Online education, Text mining, Chatbot

Type of contribution: Best PBL Practice

1 Introduction

The effectiveness of problem-based learning and project-based learning (both abbreviated to PBL) has been accepted widely. PBL is the learner centred instructional method in which students work in collaborative groups to identify what they need to learn (Hmelo-Silver et al., 2012). The teacher acts to facilitate the learning process rather than to provide knowledge. Aalborg University in Denmark implements PBL as the basic educational methodology throughout its engineering program (Fink, 1999). Worcester Polytechnic Institute in USA put project courses in curriculum (Tohoku University, 2017). PBL is one of the key components to guarantee the quality of engineering design education and to satisfy ABET (Accreditation Board for Engineering and Technology) criteria set for the engineering education curriculum. ABET and JABEE (Japan Accreditation Board for Engineering Education) define engineering design as the process of devising a system, component, or the process to meet desired needs (ABET, 2020). CDIO also sets standards for engineering education which includes design-implement experiences and active learning (CDIO, 2010).

Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) focuses on developing students' active learning ability to adjust oneself to changes proactively, explore a future goal of one's own, and evaluate that goal flexibly and generally from a broad perspective (MEXT, 2013). The education which develops the competence to practice and apply the studied knowledge and skill is required. It is important to bring up the ability to tackle problem detection and solution.

Not only the contents but also the education / learning methods are changing with progress in Information and Communication Technology (ICT). Bill Gates said" Five years from now on the Web for free you'll be able to find the best lectures in the world. It will be better than any single university." at the Techonomy conference in Lake Tahoe, CA in 2010. In recent years, the classes based on lectures can be taken on-line. MOOC (Massive Open Online Courses) has spread all over the world. More than ten million learners use Cousera® or edX®. Although there are still many universities which give lectures in the old fashion class rooms, students' attitudes have also been changing. Mark Prensky describes "Our students have changed radically. Today's students are no longer the people our educational system was designed to teach (Prensky, 2001, 2010)."

Aiming at IoT application and realization of Society5.0, MEXT and the Ministry of Economy, Trade and Industry (METI) in Japan are advancing the measure for Active Learning and EdTech (coined word; Education x Technology). The Education Reform Committee of MEXT considered the innovation of the education corresponding to progress of technology and the high school reform corresponding to a new era. The Committee has proposed the following to the Cabinet; aiming at collaboration learning corresponding to every person's ability and aptitude, empirical study about effective utilization of the technology like EdTech is needed by collaboration of the school, corporations (Kyouikusaisei, 2019).

There are several web-based design platforms available. At the 7th International Research Symposium on PBL (IRSPBL) in 2018, two papers were published on using the professional platform widely used in industry (Sorensen et al., 2018), (Rodriguez-Mesa et al., 2018). Using the professional platform may be useful for getting used to the tool which the students will use at work in the future. However, we have noticed that more common communication tools are effective. There are many free communication and collaboration tools.

Practical use of AI is raised as another side of progress of digitization. AI is already familiar as not only games but speech recognition and text input assistance. There is education software which AI understands a user's character and study results, and proposes the study method. The application of data mining or text mining has been reported in education fields (Agrawal et al., 2013), (Ito et al., 2018).

What kind of composition and tools are required to realize online PBL education taking advantage of the merit of digitalization? Digitalization differs from digitization: digitization just means analogue-to-digital conversion while digitalization means transforming the system using digital technologies. The goal of this paper is to propose the digitalization tools which realize the online PBL education system using AI instead of teachers' direct instruction. Our proposing system is based on our education experience and the literature review. Although most of the literatures extracted by the key word "PBL + AI" are about PBL for learning AI, the application of the AI to education has been studied for many years: Japanese Society for Artificial Intelligence published the special issue on "Collaborative Learning and AI" in 2008 (Japanese Society for Artificial Intelligence, 2008). As the application of AI developed greatly in recent years, we have reviewed many articles including commercial use. The proposed system is under construction which uses chatbots and text mining tool as the AI engine. Students access to Slack and work on the project team channel. The AI engine acts as the chatbots using the course materials and know-how database.

The rest of the paper is organized as follows. Section 2 elaborates on the background for the proposal, specifically focusing on PBL programs and pedagogical system in KIT. We also review trends of application of AI to education fields. Section 3 proposes on-line PBL education system which uses AI. Some of the system components will be introduced. Section 4 presents trial results of the text mining tool and Slack Apps. Finally, section 5 summarizes conclusion.

2 Background

2.1 PBL Program in KIT

Kanazawa Institute of Technology (KIT) sets PBL as the backbone of the curriculum and names it Project Design Program (PD), which consists of 5 compulsory courses as shown in Table 1. These courses are held in 12 departments in all four colleges: College of Engineering, College of Informatics and Human Communication, College of Architecture, and College of Bioscience and Chemistry (Ito et al., 2015), (Ito et al., 2016). The focus of this program is the use of the design process to solve the problems, and at the same time, to enhance students' innovation skills rather than specific engineering theories. Each project team in each PD course consist of four to six students and sets up their own project theme. That means more than 250 projects are set up in each PD course every year.

Table 1: Project Design Program Courses and Main Contents.

Grade	Freshman		Sophomore		Senior
Course	PD Introduction	PD 1	PD 2	PDIO	PD 3
Main Contents	Experiment methods	Idea creation	Idea into shape	Verification experiments	Graduation thesis

The PD program also pays attention to "Ba", a Japanese term for "a shared space for emerging relationships" (Nonaka et al., 1998), (Nonaka et al., 2000). "Ba" can be a physical meeting space, a virtual internet space, or a shared experience space. Individual and/or collective knowledge can be created through the spiral process of interactions. KIT has 24-hour available study rooms, team work spaces and facilities for designing and producing models/ prototypes.

2.2 e-Syllabus System in KIT

Each university shows its students the syllabus which shows the contents of learning of each course. Many syllabuses show what kind of contents students study by the class of each week. However, they are only shown at the time of course introduction or the first classes.

Our university launched the e-Syllabus in 2016 (KIT, 2020). The teachers who take charge of their coursework are utilizing the e-Syllabus as one of communication tools with students and as the system which is useful for students' active learning.

The example of an e-Syllabus image is shown in Figure 1. E-Syllabus displays the contents of learning of weekly classes with the guide of learning targets, scholastic evaluation method, and preferred achievement, etc. The teacher in charge can upload handouts or visual contents, and carry out tests and questionnaires in the contents area of weekly learning. Moodle (Modular Object-Oriented Dynamic Learning Environment) is widely used as Learning Management System (LMS) in e-learning. Video streaming is also used as one of the learning contents in e-learning. E-Syllabus can also carry out links with these contents.

Teachers can browse not only the e-Syllabuses of their own classes but also those of other classes. Teachers can share the each other's contents of classes and the operation method through e-Syllabuses. E-Syllabus is a powerful tool when carrying out flipped learning and active learning. The teacher uploads preparation teaching materials and movies before the class, and gives assignments. Students prepare their lessons by e-Syllabus, and participate in the class. The teacher does the quiz which confirms preparation results, receives questions from students or guides discussion by students in school hours. He can carry out quiz and questionnaires by e-Syllabus in school hours, and can confirm degree of comprehension on the scene. The usage of e-Syllabus can be measured by access log. Authors reported that the e-Syllabus is one of communication tools with students and is useful for students' active learning (Ito et al., 2019).

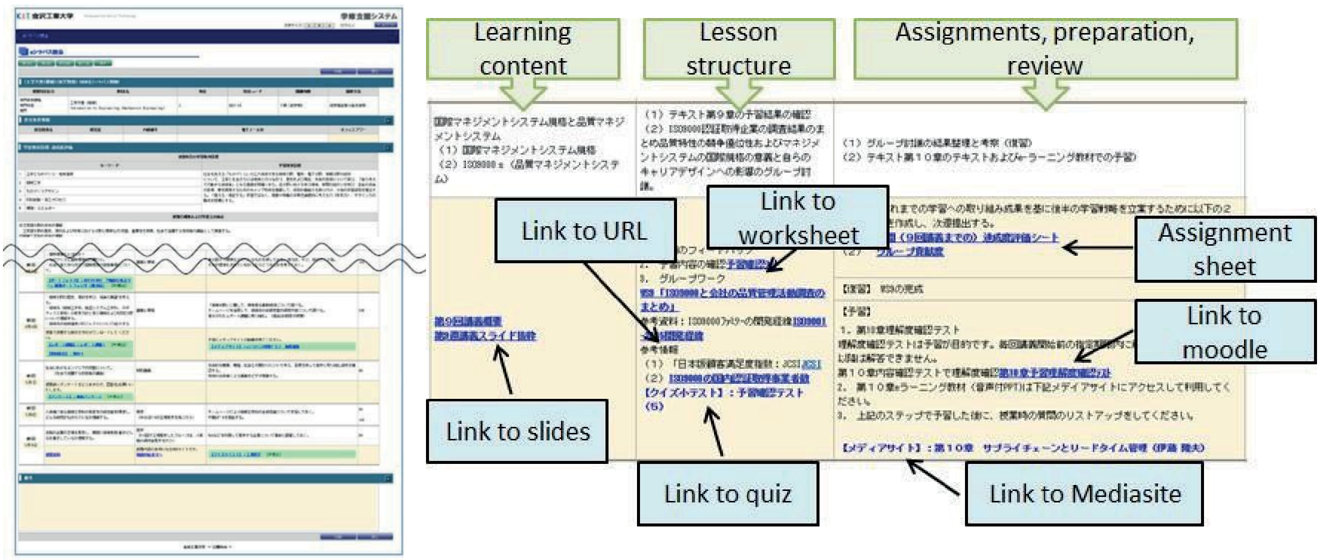

Figure 1: Example of e-Syllabus

2.3 AI System in Education

AI (Artificial intelligence) has accomplished remarkable development and attracts attention. Application of AI to education fields is also progressing. A popular commercialized AI application in education is an intelligent tutoring system that analyse students' responses to specific questions and changes learning contents based on the answers. For example, Media5 corporation provides learning materials for high school students which use AI to support best learning methods for each student (Media5, 2020). Students answer some questions before learning video materials, and AI navigates best learning methods to improve their learning scores.

Branislav Srdanovic wrote on eLearning Industry in 2017 that AI is quickly changing education and eLearning and chatbots are becoming incredibly useful learning tools (Srdanovic, 2017). He listed the three most important ways how AI and chatbots can improve education: essay scoring, spaced interval learning and student feedback, and professor assessment.

Robin Singh wrote an article on Chatbots Magazine in 2018 (Singh, 2018). In the article he pointed that chatbots with AI technology can be used to teach the students by turning a lecture in a series of messages to make it look like a standardized chat conversation. The bot may repeatedly assess the level of understanding of the student and present the next part of the lecture accordingly. He pointed out 7 ways in which artificial intelligence and chatbots are influencing the education: Learning through chatbots, Enhanced student engagement, Smart feedbacks, Efficient teaching assistants, Instant help to students, Better student support and Up-to-date information for the institutions.

Areeba Khan announced Chatbot makers utilize artificial intelligence and the latest conversational design to create bots that can communicate with students as well as teach them (Khan, 2019).

Asha Pandey mentioned more applications of AI for learning in 2020 (Pandey, 2020). The use of AI in learner analytics is being leveraged to offer highly custom learning pathways for the learners. Based on the data of their content consumption pattern, further recommendations can be made.

KIT uses IBM AI platform Watson to realize Cognitive Campus referred as “KIT COG”; Watson searches over one million items in the archival records of KIT graduates to select a student with a similar academic background and give appropriate advice to the student based on the data taken from the record. KIT has accumulated students’ study outcomes and portfolio data using e-Syllabus for many years. Learning portfolio data of 7,000 students accumulate every year. Based on these data, Watson API can perform personality diagnosis of students and teachers instruct students using their data (IBM, 2017).

3 On-line PBL Education System

Based on the background survey, we propose the on-line PBL education system which combines PBL and digitalized learning. Taking advantage of the rich instructional materials, students’ deliverables and questionnaire results of KIT PBL courses, the authors are investigating the online PBL education system which uses AI instead of instructors. There are many subjects to be solved in the systems configuration: how to prepare teaching materials, teacher know-how, and an ICT system and how to utilize AI in the system. In usual lessons based on lectures, the video contents of lessons are distributed to students by Web server. However, in PBL education, the role of the teacher as a facilitator is important and the bidirectional communication between the teacher and students is needed. Completely different approach from having a class on-line in lecture form is required for on-line PBL.

The composition of the education system under plan is shown in Figure 2. Students access to the digital platform and work on the project team database. The AI engine acts as the facilitator on each project using the course materials and know-how database. Text mining and chatbots serve as main components of AI engine. Some components are already prepared and there are some programs and linkages under investigation.

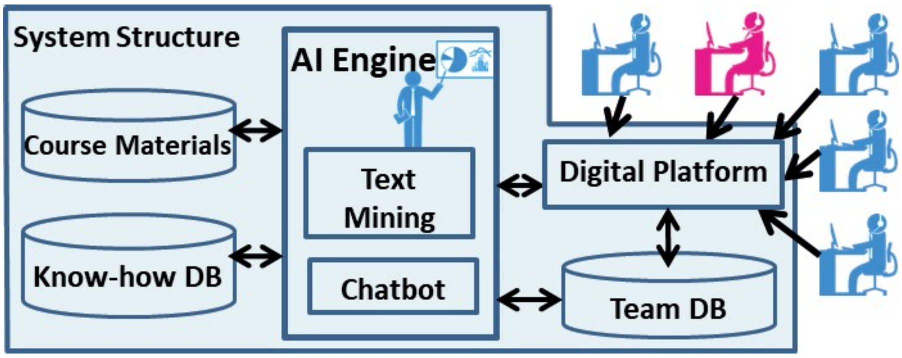

Figure 2: Composition of the on-line PBL education system

3.1 Digital Platform

As for the digital platform, we considered a commercial design platform like Dassault Systems' ILICE™ at first. The professional platform is widely used in industry and it may be good for engineering students to be accustomed with the platform. The pilot studies of using these platforms were reported in 2018 (Sorensen, , 2018), (Rodriguez-Mesa, 2018). However, from carrying out 250 or more projects in each term, we thought that the platform to which a student is more used is better. Projects of freshmen and sophomores are not necessarily engineering or designing mechanical things. They do not need to use the professional design tools in their projects.

We considered using the e-Syllabus system as a next candidate. As mentioned in 2.2, teachers and students use it as one of communication tools. Some teachers make students register the results of team activities into the e-Syllabus system, and comment on the result. However, it is the complicated system to make a pilot user interface and an application on it.

We decided to try the chat system Slack (Slack, 2020). Slack is excellent in a user interface, and integration with other services is easy. It can be easily accessed from the e-Syllabus. Use of Slack has spread not only among companies but among students because of its ease of use and basically free of charge. A "Channel" can be set up for each project and project members communicate and work in the channel. All of the conversation and produced data are recorded as a searchable team data.

3.2 Course Materials and Know-how DB

More than 6,500 reports are stored in the web server as the students output of the four Project Design Program courses from 2012 to 2018: about 1,500 PD Introduction experiment reports, 1,700 PD1 design reports, 2,000 PD2 implementation documents and 1,400 PDIO project repots. The themes of projects are various from an airplane or a car even to sightseeing and food. Keywords are extracted from each report by text mining, and they are given to the report as index. There is also the database which teachers prepared the principles and laws of physics and chemistry. Teachers' instruction materials including PowerPoint class slides are also on the e-Syllabus and the web server. These data can be saved as course materials and used as the know-how database.

3.3 AI Engine

The AI engine facilitates project activities instead of teachers or helping teachers. It analyses course materials and know-how data using text mining. It also analyses the ongoing project data in the team database. Matching these data, the AI engine recommends the course materials and references to the project.

Chatbots are used to answer questions from the students, monitor their activities on the project and give them feedbacks. Chatbots behave like teachers who take charge of the projects.

4 Findings and Discussion

Although the proposed on-line PBL education system is still in preparation for construction, there are some achievements of the system components. We introduce some of the result: text mining analysis of the PBL class questionnaire, and the example of application of Slack in extracurricular project activities.

4.1 Text Mining

Text mining has been hard to use for many teachers. However, there are some commercial based text mining tools available that can be used to analyse voices of customers from surveys or social media. We have used Mieruka-Engine™ for analysing the free descriptive answers of students who took PD courses. Mieruka-Engine™ claims as No.1 text mining tool in Japan (Mieruka-Engine™ is a registered trademark of Plus Alpha Consulting Co., Ltd.) (Plus Alpha Consulting Co.,Ltd., 2020). Word frequency is automatically calculated and the word mapping shows the relationship between words visually. The size of the word circle represents the word frequency. The relationships between words are shown as connecting lines. We can compare the word frequency or word mapping using categories like departments or project themes. We can save the word frequency results in Excel format.

The example which analysed the questionnaire of PD Introduction class by text mining is shown in Figure 3. Extracted top ten word counts and word mapping are shown. The words of “team” “cooperate” and “ability” are top three words which share 13.8%, 10.1%, and 9.8% respectively. Word mapping shows a close connection of “team” and “cooperate.” The mapping also shows that “team” is connected with “assignment.” “ability” is connected with “report”, “communication” and “presentation.” From the results of text mining, the relationship between “communication”, “teamwork” and “team assessments” is verified. The word mapping shows that students felt the importance of reporting, communication and presentation skills.

The example results show PD courses are useful for acquisition of special capabilities and basic abilities to work in society.

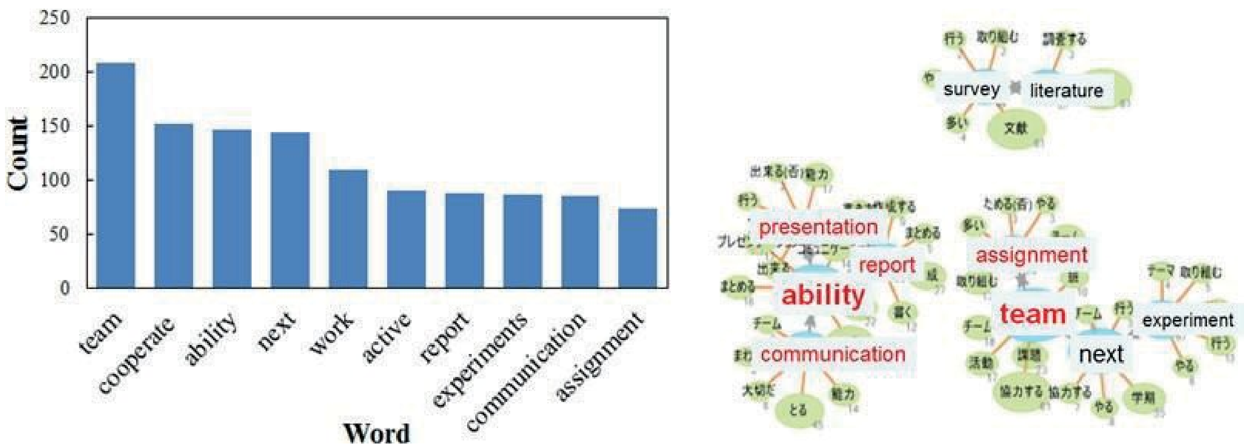

Figure 3: Example of text mining results; word count and word mapping of PD Intro

4.2 Chatbots and Applications

Chatbots can be used as the virtual facilitators. Using Slack as the digital platform, chatbots can be easily integrated on the platform. Slack calls chatbots a Slack App and handles as one of regular applications. “PBL teacher” chatbot is under preparation in order to reply to students’ questions instead of teachers. It will extract keywords in the questions and find related materials which best match the keywords from the database. One example question is, “How can we make a poster of our project?”. The chatbot answers “You can find a template and a sample poster in this link …” The chatbot may recommends “You can find some posters relevant to your project here …” Such a program will reduce teachers’ support work and students can learn with the chatbot.

Slack also has the linkage with Trello which is the project management tool. Project members can share to-do list and the schedule.

Although the on-line PBL education system is still a development phase, the students of the extra-curricular smart city project used Slack and Trello as the communication and project management tool. Since the students are accustomed with SNS, they used the tool comfortably and carried out the project even if they worked in separate place. Because the program has not been made yet, the human teacher acted as “PBL teacher” chatbot and facilitated the project. Once the program of “PBL teacher” is completed, it will be useful as a facilitator of project activities.

It may be hard to construct “PBL teacher” combining Mieruka-Engine™ and Slack. We are planning to make the application using TF-IDF (Term Frequency, Inverse Document Frequency) which extract keywords from students’ exchange on Slack and make suggestions to promote their projects. TF-IDF is one of the algorithm to find the most important words in a text document (Loria, 2013). PBL principles will be covered by “PBL teacher”.

5 Conclusions

Progress of digitization and development of ICT are changing education. We propose the on-line PBL education system, which consists of the digital platform, the team database, the AI engine, the course materials and know-how database. Text mining and chatbots serve as main components of AI engine. The system is still a development phase. However, some components are already prepared and some achievements of the components are shown.

In PBL, the platform as the place of students' communication is required. Students get used and are familiar with communication by SNS. As projects of Project Design Program Courses of KIT for freshmen and sophomores are various not only in the engineering field, the on-line PBL education system using Slack and chatbots is proposed instead of web-based design platforms. Chatbots can act as the facilitators. The students of the extra-curricular smart city project used Slack and Trello as the communication and project management tool.

The example of text mining usage is also shown. Combining these usages with chatbots based on course materials and know-how database can be the on-line PBL education system.

Digitalization of the place of students' communication and teachers’ know-how can realize the online PBL education. Furthermore, many works are required including the valuation method of project activities besides chatbots program creation.

6 Acknowledgements

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The Impact of E-Learning in the running of Laboratory-based Programmes in Higher Educational Institutions. A Case Study of the Department of Fisheries and Watershed Management, KNUST, KUMASI, Ghana

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Abstract

The increasing quest for tertiary education in Ghana has assumed an overwhelming magnitude in recent time, mounting pressure on public university management to increase enrolment. Kwame Nkrumah University of Science and Technology (KNUST), one of the highest ranked public university in Ghana and West-Africa has been injecting resources to expand facilities to cater for the increasing student enrolment. Various departments have had a quadrupling of student population, overstretching learning facilities. Departments that run practical-based programmes in studio or laboratory environments are challenged with the appropriation of best systems that can aid teaching and learning without splitting classes into groups that negatively affect skill acquisition. In the Department of Fisheries and Watershed Management, the system of e-learning has been adopted to blend the face-to-face traditional system of teaching and learning. The impact of this blended approach on the smooth running of its programmes is what is being shared in this presentation. This paper focuses on the digitisation of video materials on field practical activities, documentation of relevant literature, the design of strategies adopted for the creation of the e-learning site and the impact of this approach on students in developing skills for problem solving.

Keywords: Increasing Student Enrolment; Practical-based Programmes; E-learning; Blended approach; Digitisation of Video Materials

Type of contribution: PBL Practice

1 Introduction

Most educational institutions in developing countries that run distance educational programmes relate more with theory-based courses whose learning materials are easy to package and deliver on online platforms. The print technology has been the predominant mode for delivering instructional and learning materials of such theory-based courses to learners. Since this technology has a limitation on the capacity to deliver practical skills effectively to the learner, it has been very challenging for institutions whose courses are predominantly studio, laboratory or field practical based, to incorporate audio- visuals of their practical activities to facilitate problem-based learning on online platforms. This was the motivation of the authors of this paper who are members of the local task force in the Erasmus+ (EEISHEA) Project in Ghana, trained in the areas of e-learning and sustainability.

This paper discusses the schemes adopted for bringing field practical activities of the Department of Fisheries and Watershed Management into the classroom space to reduce the rate of field trips as well as the turn-around time for students to acquire practical skills, and the impact of this system on the student's problem-based learning activities. Adobe Dreamweaver CS6, an Integrated Development Environment (IDE) software and TechSmith Camtasia Studio version 2018 were used for this project.

Adobe Dreamweaver CS6 is a software with excellent tools for web designing and multimedia content material development. It provides tools that enable web designers to develop simple interactive e- learning sites that can deliver all the major learning elements, which are sound, video, text and still pictures from a single interface. This project was made possible with the use of Frameset system and two language systems; Hyper Text Mark-up Language (HTML) (Domantas, 2019 a) and JavaScript programming language (Domantas, 2019 b).

Camtasia Studio is an excellent software for creating and editing videos for educational purposes because it offers tools for incorporating annotated documents to facilitate Distance Learning on the Web platform. The videos from Camtasia display with crystal-clear effect at any screen size on Web pages, blogs, CDs, or portable devices like the iPod. It also offers tools for computer screen recordings that can capture cursor movements, menu selections, pop-up and typing, and any other action seen on the screen. In addition to screen recording, Camtasia recorder allows the user to draw on the screen and add effects while recording (KSU, 2017). This is the justification for choosing Camtasia for this project against all the other available video creating software.

2 Methodology

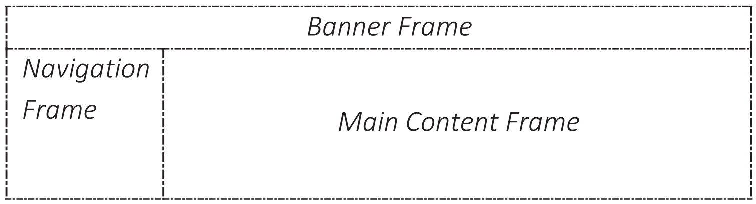
2.1 Adobe Dreamweaver CS6 Capabilities

The framesets system in Dreamweaver was used for this project because there was the need to display multiple views in the same interface so that some views will be made static whilst others will scroll independently from the others or the content replaced without affecting the entire window. For example, within the same window, a frame can be inserted at the header to display a static banner, one at the left or right to serve as the navigation frame and a large area to represent the main content frame that can be scrolled through (fig 1, examples 1 and 2). Developing a website with framesets not only make website well organised but allows users to access the information more easily (O'Leary, 2000).

2.2 Techsmith Camtasia Studio Version 2018

Edited videos were rendered in MP4 Smart player 'HTML5' format for easy accessibility on smart phones aside the normal web browsers. Camtasia attaches to each MP4 video file, Cascading style sheet document, an Extensible Mark-up Language (XML) Document and JavaScript to control the behaviour of the video in the web browser.

Example 1



Example 2

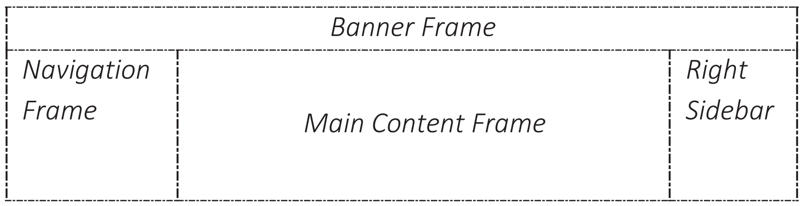


Figure 1: Frame Layout

2.3 Impact on Students Problem-based Learning Activities

A focus group discussion was conducted by the authors to solicit the views of students on this approach to learning. Twelve students representing thirty percent (30%) of the entire class participated in the discussion.

3 Results and Discussion

2.4 The Site Interface

Four frames characterised the interface of the site. The Banner frame, Navigation frame, Main content frame and the Instructors frame. The banner frame and Instructors frame were static, whilst the navigation and the main content frame were scrollable.

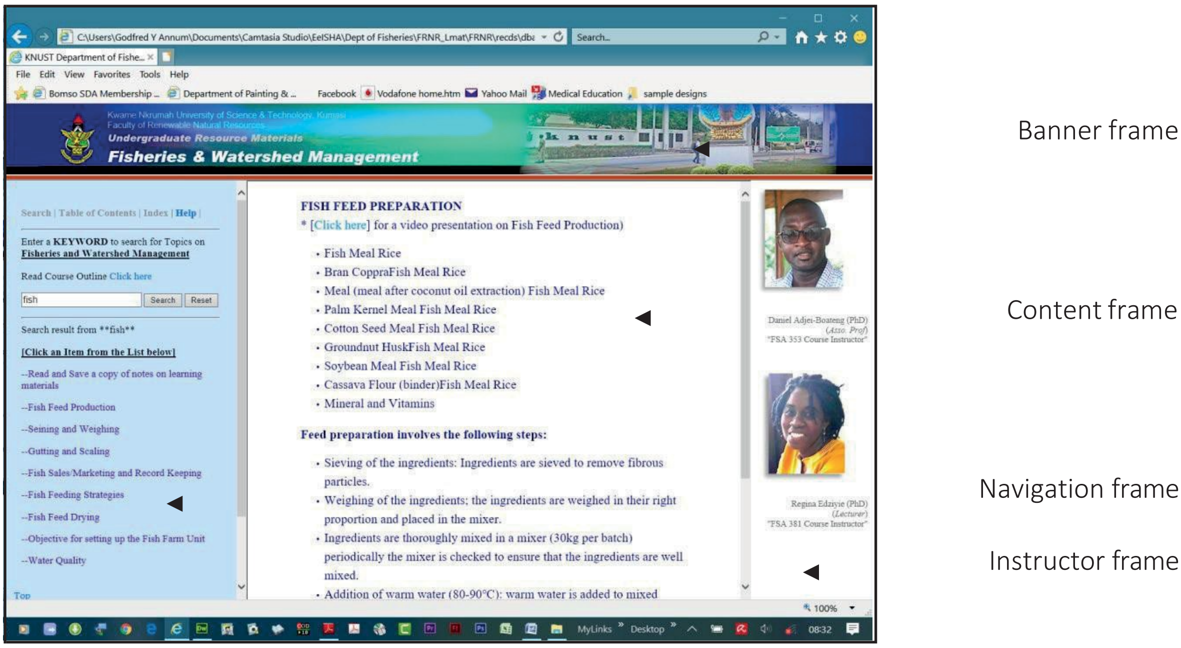


Figure 2: Site Interface
Source: https://webapps.knust.edu.gh/lmat/FRNR_Lmat/FRNR_index.html

The 'banner frame' displays the identity of the institution. The 'Instructors frame' displays the identity of the course instructor. The 'main content frame' loads the learning materials. The 'navigation frame' displays a search engine that enables students to search from the database, topics on the subject of study by typing in any keyword associated with the topic. The Hyper Text Mark-up Language was used to format the banner, instructor and the content frames. However, search engine in the 'navigation frame' was programmed with JavaScript language, based on Adobe JS CDATA System.

2.5 Streaming of Video Materials

When the link to a video supporting any learning material is clicked in the content frame, that accompanying video is loaded into a window (fig 3) to stream alongside the main interface. This action is powered by a simple Hyper Text Mark-up Language script.

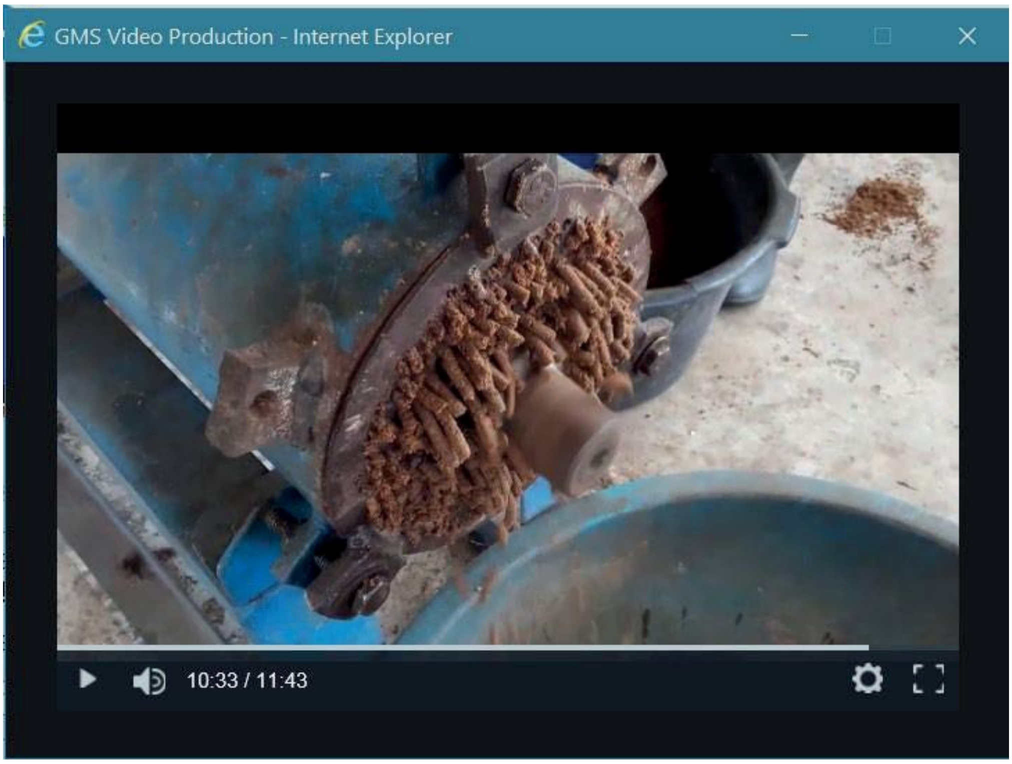


Figure 3: Window displaying Video on production of Feed Pellets

2.6 The Search Engine Functionality

When any Keyword(s) relating to topics in "Fisheries and Watershed Management Course" including the Course Code "Number" is/are typed in the search text box in the navigation frame, the system will filter from the database, only reports that capture the keyword. When the Course Code **'353', '354', '381'** or **'382'** is entered in the search engine, it will filter all related topics in the database.

It is not automatic that any word keyed in the search engine box will filter a topic. "Topics" of notes that contain the searched word(s) will populate below the search text box. The topics that are most likely to contain the keyword required will populate at the top of the list. To display the notes in the content frame, the user has to click the "topic" in the search results. The link to stream the video material supporting the literature is pinned to the bottom section of the notes.

Guiding Principles on Keywords

- If one types more than one word separated by spaces, the search engine will populate topics that contain the words typed. For example, if one types "fish net," the search engine will populate all topics containing both "fish" and "net".
- The Search engine does not do word-stemming. For example, if you search for "fish" the search will not match "fishing" or "fishers".
- Matches are not case-sensitive; so "Water" is the same as "water"
- Topics that include matches in their titles are ranked higher in the search results. The number of matches in a topic also affects its rank.

- The Search engine ignores all punctuation characters except periods within words and underscores.

Short and Common words

The Search engine filters and ignores very common words you type in the Search text box. Often called "*stop words*", these common words usually don't improve the search results. Examples of stop words include "the," "of," "as," and "when." In addition, the Search engine ignores one and two- character words (unless the 2-character word includes a digit). For example, if one types "weighing of fishes" in the text box, the search excludes the word "of" and displays pages that contain only "weighing," and "fishes"

2.7 Impact on Students Learning Activities

The students were of the view that the adoption of the blended e-learning approach will have a positive impact on their learning and skills acquisition. It had reduced the turn-around time for practical skills such as feed formulation and preparation as well as water quality sampling and testing in the laboratory. The videos of these practical activities are the first sources of instructional materials for students in preparation for the conduct of practical and field activities.

Responses from the students on their assessment of the video materials and its impact on their learning and problem-solving skills indicated that, the videos have become useful resources for promoting learning and developing problem solving skills. However, they were of the view that the videos should not replace the time needed for hands-on practice.

Critical issues that were raised from the focus group discussions were:

1) **Duration/Timing**: The videos have to be long enough to adequately explain the concept or process being explained but not too long to lose the attention of the students. The release of these videos have to be timed so that they come at the same time when the concepts/processes they cover are addressed in class.
2) **Feedback**: The students pointed out that there are a lot of videos on-line which they use to support learning, but a major limitation is getting answers to questions that arises while they watch these videos. In instances where they could contact the instructors, the feedback was not timely. If the videos are rightly timed, then some of these questions could be addressed in class to the benefit of other students.
3) **Scale:** Images in videos have to be scaled appropriately for clarity in the procedures they seek to demonstrate. For example one student stated that 'before she ever dissected a fish to study the pituitary gland for artificial reproduction, she had to watch several videos on the subject, but when she had to conduct the practical activity in the laboratory, she was surprised at the size of the gland she saw and how confused she was in handling the procedures'.
4) **Other issues**: Although, e-learning materials especially the videos are effective, it does not inform students about some vital things. Examples include how fragile fingerlings are, common errors that occur in practice and ways to deal with them. Another important issue raised was the potential of the on-line materials to inculcate in the students, the ability to develop their skills in critiquing existing methodologies with the view of improving on common methodologies applied

in problem identification and solution. These on-line materials can help students gain access to 'practices' that they would have in no other way had access to.

This group of students are required to have only one industrial attachment in the entire four-year period of study. It is actually difficult to find placement or bear the cost of financing more than the mandatory industrial attachment. The students therefore admitted that these videos are useful resources for learning about practices in the industry and advocated for the entire practical lessons in the programme to be captured in videos.

3 Conclusion

Although there are appropriate technologies like video-conferencing that can facilitate distance- learning activities in practically oriented tertiary institutions, it will be very challenging for practical based institutions in Ghana to run or adopt these systems of learning. Financial capacity is the obvious difficulty that threaten its success. The need for developing the technological acumen to appropriate simple but effective delivery technologies that incorporate, Graphics, Sound, Video and Text documents in the development of course materials for distance learners should be embraced. The adoption of this e-learning approach to enhance the practical skills of students was timely in the wake of Covid-19, where the semester was truncated mid-March and there was a mandatory presidential directive for all instructional and learning materials to be delivered online. The authors have demonstrated that it is possible to develop a computer- based educational technology that can help courses that dwell much on industrial attachment to build capacity for in skills and knowledge base needed for problem-based learning, to bring the field practical activities into the classroomdomain.

3.1 Recommendation

It is however worth noting that, the success of running this system of e-learning immensely depends on high-speed broadband wireless facilities to enable smooth streaming of video materials. The current state of slow internet speeds in small towns and rural communities and even on KNUST Campus is a challenge that has to be surmounted for this approach to be effective.

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Preparing engineering students for collaborative project-work: Piloting an online course on PBL and project management

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Abstract

MAREENE is an international Master programme on *Reliability based structural MAintenance for marine Renewable ENErgy*, delivered at Université de Nantes (France). This Master programme is a one-year programme that completes a first year to deliver a Master degree. It is developed in collaboration with Aalborg University (AAU), Norwegian University of Science and Technology (NTNU) and the School of Mechanical & Materials Engineering of the College of Engineering and Architecture of University College Dublin (UCD). The programme curriculum is problem-based and project-organised (PBL), where small groups of students solve real and authentic problems within civil and marine engineering through a project of two ECTS per semester. Besides the project, students also have online courses, which provide technical knowledge and support their project work, namely in PBL and project management. Université de Nantes is running for the first time a Master engineering programme with a PBL curriculum, where both students and staff lack, or have limited, experience on how to manage and organise learning in a PBL environment. Therefore, the MAREENE programme includes a 15 h, fully online course on PBL and project management as part of the project module, the overall goal of which is to provide students the knowledge and tools needed to develop the skills and competences to carry out a problem-based project successfully. The course is student-centred, problem-oriented and focused on students' experiences and needs. This paper describes the framework of the PBL online course, its learning principles and evaluation. The course evaluation targeted students who participate in the course, and their responses were collected through a questionnaire distributed through Moodle. Results indicate that course structure, materials and assignments support student learning and have met their expectations from a moderate to a large extent. In addition, they also consider the course and topics addressed relevant, including for future projects they will be involved in.

Keywords: Online course, PBL and project management, student learning.

Type of contribution: *PBL best practice*

1 Introduction

The need for a more student-centred curriculum in engineering education is leading to the integration of problem-based, project-organised learning (PBL) and the establishment of new teaching practices focused in student learning and development. The popularity of PBL has been rising around the world and is mainly due to the competences and skills students develop, namely problem-solving skills, communication, teamwork, critical thinking, self-directed learning and lifelong learning, among others. Social and professional trends, such as digitalisation, automation and sustainability, call for the development of such skills to enable future engineers to perform and operate in a globalised and volatile society and working environments (Motyl, Baronio, Uberti, Speranza, & Filippi, 2017; Richert et al., 2016; United Nations, 2015). This means that traditional, transmissive and teacher-centred curricula and practices are changing by integrating PBL and developing a more student-centred curriculum. However, such transitions require a change in teachers' and students' roles, type of learning outcomes, assessment, learning and teaching activities and learning spaces. The development of resources and activities to support student learning and teachers are central for a successful integration of PBL. Examples of resources and activities to support both academic staff and students are face-to-face training workshops and online courses, which provide them with knowledge and skills to manage and facilitate learning (Cheaney & Ingebritsen, 2005; Kolmos, Graaff, & Du, 2009; Savin-Baden, 2000, 2007).

Furthermore, the future of education is digital, where the use of technology, digital media and social media, namely computers, smart phones, online resources and platforms to collaborate, communicate and access information is part of how 21st century students learn. Furthermore, the combination of continuous emergence and innovation of communication technologies and the need for continuous learning has been contributing to the boom of the digital learning. Digital learning enables autonomous learners to learn anywhere (e.g. distance learning) and anytime (e.g. asynchronous learning). It has also been proved that interaction, one of the most important components of any learning experience, is one of the major constructs of distance learning. However, the "boom" of digital learning does not come without concerns, namely effectiveness of learning settings and opportunities created, alignment between learning intentions, assessment and development of skills (Garrison, 2000; Savin-Baden, 2007; Vrasidas, 2000; Warschauer, 2007).

In summary, as engineering education develops towards more student-centred learning and towards more autonomous and independent learners, digital learning creates new learning spaces and possibilities. For example, it provides the opportunity to develop resources to support academic staff and students integrating and managing learning in a PBL environment, such as online courses. In addition, such courses can be delivered by PBL experts and at international scale. This paper reports the example of a PBL online course, called PBL and Project Management, which is part of MAREENE, an international Master programme. MAREENE is the acronym for Reliability based structural Maintenance for marine Renewable ENErgy, and is delivered at Université de Nantes (France) and developed in collaboration with Aalborg University (AAU), Norwegian University of Science and Technology (NTNU) and the School of Mechanical & Materials Engineering of the College of Engineering and Architecture of University College Dublin (UCD). It is a one-year programme that completes a first year to deliver a Master degree. Its curriculum is problem- based and project-organised (PBL), where small groups of students solve real and authentic problems within civil and marine engineering through a project of two ECTS per semester. Besides the project, students also have online courses, which provide technical knowledge and support to their project work, such as the PBL and Project Management online course. The need for an online course on PBL and project management emerges from Université de Nantes' students and staff lack, or have limited, experience on how to manage and organise learning in a PBL environment. This paper describes an online course and its learning principles, followed by reflections of its implementation and evaluation.

2 Description of online course "*PBL and Project Management*"

The course is student-centred, problem-oriented and focused on students' experiences and needs. Its overall goal is to provide the knowledge and tools students need to develop the skills and competences to carry out a team-based, problem-oriented project successfully. PBL and Project Management is a short, fully online course, with a duration of 15 hours, and is part of a two ECTS project module per semester. The course addresses the topics PBL, collaboration, project management, academic co-writing and documentation, which are core elements of PBL working processes. Table 1 presents the course learning outcomes.

Table 1. Learning outcomes

- Define collaborative, problem-based project work
- Define group collaboration, problem formulation and project work, documentation and academic co-writing processes in a PBL environment
- Identify challenges in collaboration, problem formulation and project work, documentation and academic co-writing
- Develop strategies to manage learning and group working processes, namely collaboration, problem formulation and project work, documentation and academic co-writing
- Implement the strategies to improve learning and group working processes, namely collaboration, problem formulation and project work, documentation and academic co-writing
- Discuss and reflect on the strategies implemented to improve learning and group working processes
- Reflect on group practices and provide critical feedback to peers

The course is organised in four online seminars, with assignments in between that are carried out individually and as a group (Table 2).

Table 2. Course activities and respective descriptions

Activity	Description
Online seminar (OS1): Kick-off and introduction	- Introduction to the course: schedule, structure, goals and assignments - Brief definition of PBL and its elements, namely collaboration, problem orientation and project work. - Overview of Assignment 1
Assignment 1: Understand PBL principles and practice	- PREPARATION: Read the booklet about the Aalborg University (AAU) PBL model, pages 4 to 15. (Booklet available: https://www.aau.dk/digitalAssets/148/148025_pbl-aalborg-model_uk.pdf and in the course Moodle) - INDIVIDUAL TASK(S): After preparation, answer the following questions: i) Define PBL in one word. ii) What are the aspects of PBL you find hard to understand, or that lack concrete examples for/in practice? (max. 20 words) iii) What are the three aspects you find most positive about the AAU PBL model? Why? (max. 30 words) iv) What are the three aspects you find most challenging about the AAU PBL model? Why? (max. 30 words)
Online seminar (OS2): PBL working processes and associated challenges	- Summary of understanding and expectations of PBL - Define PBL principles and practice - Define collaboration, problem orientation and project work, documentation and co-writing - Overview of Assignment 2
Assignment 2: Observation of PBL challenge in practice	- IDENTIFY YOUR PBL CHALLENGE - GROUP TASK(S) 1. Why the challenge is a challenge? 2. Design an agenda, or framework, to describe how your group practises the PBL challenge. (When designing the agenda, or framework, please consider the following: how the challenge is practised in the group; what works and why; and what does not work and why) - INDIVIDUAL TASK(S): 1. Observe the group practising the PBL challenge. 2. Write notes of your observations according to the above agenda (or framework)..
Online seminar (OS3): Develop action plans to address PBL challenges	-Summary of PBL challenges and group practice -Identify PBL challenges based on Assignment 2 - Identify tools and resources to improve collaboration, problem formulation and project work,

Activity	Description
	documentation and academic co-writing - Overview of Assignment 3
Assignment 3: Plan of action to improve PBL working processes	- PLAN FOR IDENTIFIED CHALLENGE - GROUP TASK(S) 1. Go through the links and resources related with the PBL working process you want to improve (list is in Moodle). 2. Based on examples of tools given in the links and resources, design a plan to improve a PBL working process. Describe your plan here. 3. Implement the plan. - INDIVIDUAL TASK(S) Write down your reflections on how the plan worked in practice, considering the following: 1. What are the main problems the plan aimed to address? 2. What did the plan actually improve and why? 3. What did not work with the plan and why? 4. What can be improved further in your PBL working processes and how?
Online seminar (OS4): Strategies to address PBL challenges and course summary	- Summary of online seminars and assignments - Overview of "toolbox" catalogue to address PBL challenges - Course evaluation

The online seminars comprises three parts: summary of assignments (e.g. main lessons from assignments, peer-feedback), online seminar (e.g. introduction to session topics), and assignment overview. By their turn, the assignments are also composed by three parts: go through materials and resources, carry out the assignment, and submit assignment report. All the submitted reports and feedback notes are compiled and made available to students. Figure 1 illustrates the overall structure of course's seminars and assignments.

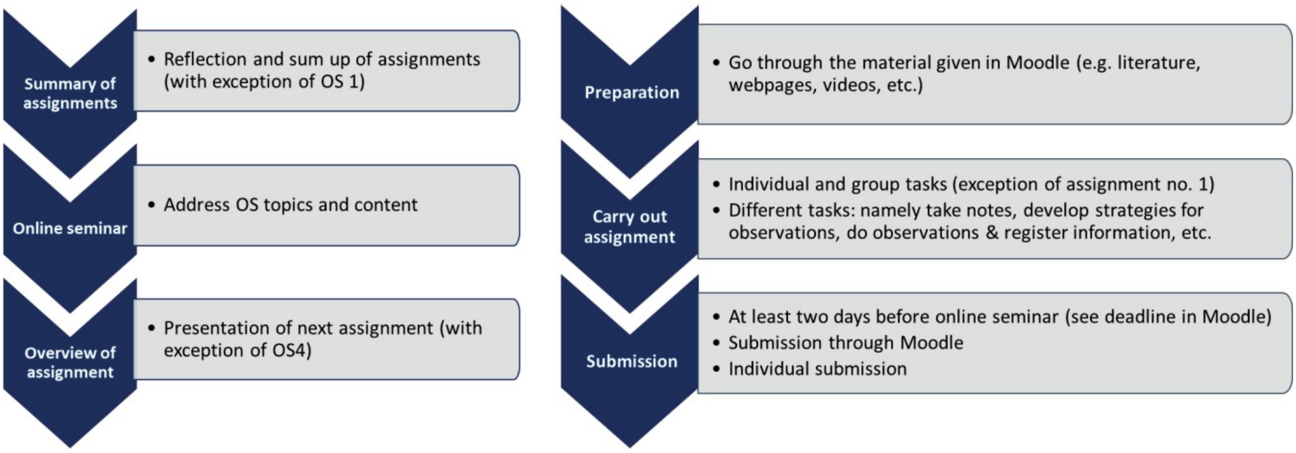

Figure 1. Online seminar and assignment overall structure

3 Guiding principles to design the online course "*PBL and Project Management*"

Chickering and Gamson's work "*Seven Principles for Good Practice in Undergraduate Education*" has been one of the main works cited by educational journals and practitioners literature when it comes to the effectiveness of distance learning (Hutchins, 2003). The seven principles are as follows (Chickering & Gamson, 1989, 1999):

1. Encourage student-faculty contact (e.g. frequent contact among teachers and students as core factor for student involvement and motivation. Teachers support student learning by, for example,

getting through rough times and keep working, foster intellectual commitment, think their own values and plans, i.e. promoter of liminal learning).

2. Encourage cooperation among students (e.g. interaction among peers is a promoter of peer learning. Good learning is collaborative and social; it increases involvement, deep learning and potentiates students' achievements (see for example Zone of Proximal Development, Vygotsky 1978)).
3. Encourage active learning (e.g. involve students actively in their own learning and carry out activities, relatable with their experiences and applicable in their daily lives).
4. Give prompt feedback (e.g. students need appropriate feedback on performance to benefit from the course and activities; need chances to reflect on what they have learned, what they still need to know, and how to assess themselves).
5. Emphasise time on task (e.g. provide opportunities for students to practise good time management by allocating realistic time to activities).
6. Communicate high expectations (e.g. expecting students to perform well becomes a self-fulfilling prophecy when teachers and institutions hold high expectations of themselves and make extra efforts).
7. Respect diverse talents and ways of learning (e.g. create variety and diversity of learning activities, materials, resources, presentation formats that create opportunities for students to show their talents and learn in ways that work for them).

The seven principles are set on a constructivist approach to learning, where students are co-constructors and responsible for their own learning, and as a social activity increasing their involvement and development. Furthermore, the teacher is not the "knowledge transmitter" but rather a facilitator who supports student learning. In summary, distance learning can be student-centred, and Chickering & Gamson's seven principles for good practice constitutes a good framework to design student-centred online courses. However, Chickering & Gamson's principles are generic, and it is left to the teacher to develop a pedagogical approach which integrates them. Problem-based, project-organised learning (PBL) is a student-centred learning approach, which ticks off all the principles stated above and provides guidelines to design online courses. Furthermore, the online course integrates a project module of a PBL curriculum; therefore, the most logical step would be to design a course about PBL and project management aligned with PBL principles.

Kolmos et al. (2009, p. 11) define PBL as problem-oriented, contextual, exemplary, experiential, participant-directed, team-based, interdisciplinary, project-organised and relating between theory-practice. The nine PBL learning principles can be clustered in three approaches: cognitive approach, content approach, collaborative approach, as Figure 1 illustrates.

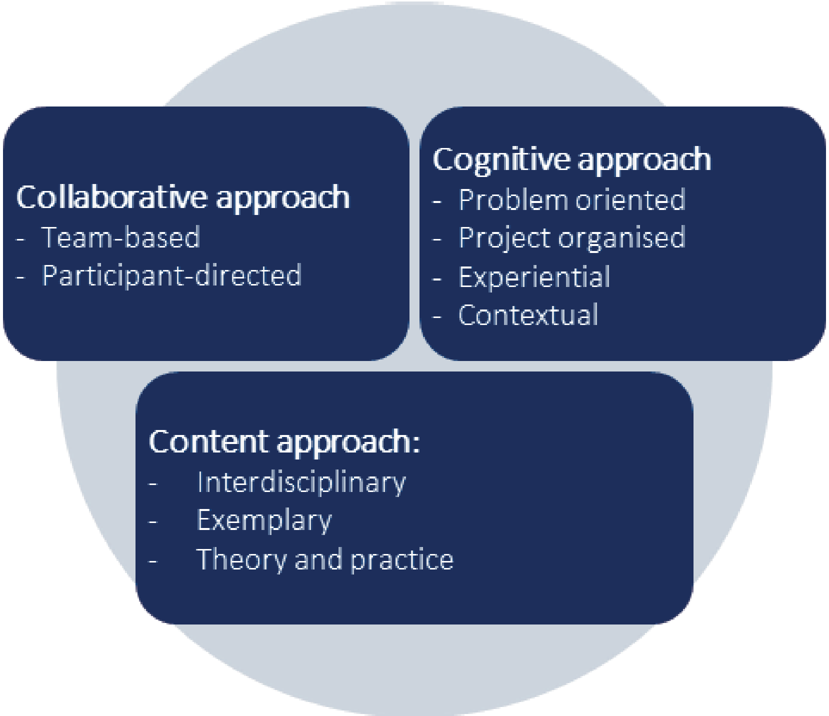

Figure 2. PBL learning principles, based on (2009, p. 11)

In the PBL approach, the learning starts with the formulation of a real problem (problem-orientation), which is solved through projects (project-organisation). Learning takes place in relation to a real context (contextual learning), and it is grounded in the learners' experience (experiential learning). The content approach concerns interdisciplinarity, exemplarity and the relationship between theory and practice. Interdisciplinarity means that the learning process crosses traditional disciplinary boundaries, whilst exemplarity means that the activities students undertake are exemplars of the overall objectives of the curriculum and through reflection and generalisation generate knowledge. The learning process entails an analytical framework in which theoretical knowledge is applied to formulate and solve problems (relation between theory and practice). Collaborative learning refers to team-based and participant-directed learning, namely that it is a social activity undertaken through dialogue and communication in which students learn from each other. Participant-directed refers to students' collective ownership of decision- making and learning processes (Kolmos et al., 2009). Table 3 describes the relation between PBL principles and the course activities.

Table 3. Relation between the online course and PBL principles (Kolmos et al., 2009)

Cognitive approach

- Problem orientation – The point of the departure for student learning is on challenges they want to address.
- Project – Online course is part of a project module and aims that knowledge and tools are applied in the project work.
- Experiential – Several activities are developed and centred on students' experiences, namely the definition of challenges, the observation of the PBL challenge in practice and implementation of action plan, etc.
- Contextual – By using students' challenges in working in a PBL environment as point of departure, learning of PBL and project management are placed in the context of their project.

Content approach:

- Interdisciplinarity – It is mainly addressed at content level.
- Exemplarity – The goal of the course is to provide knowledge and tools to manage learning in a PBL environment. The assignments include different activities which are illustrative of PBL practice principles (e.g. collaboration, co-writing and documentation, problem design, project management) and how they can be used to develop strategies to improve design in a PBL working process. The assignments are exemplary of the

procedures of how to constructively design a plan of actions to improve PBL working processes.

- Theory and practice – The online course includes diverse resources and materials that aim to provide students theoretical knowledge to develop and apply a plan of actions to improve PBL working processes in practice.

Social approach:

- Team-based – It includes group-based activities.
- Participant-directed – Students have ownership over their learning and decide which challenge to address and how.

In sum, the online course on PBL and project management adopts a PBL approach by using its principles as guiding precepts for its design. Furthermore, the organisation of the course and some of its activities can be illustrated using Kolb's learning cycle (Illeris, 2008), as Figure 3 illustrates. The cycle comprises four main stages: concrete experience, reflection and observation, abstract conceptualisation and active experimentation. *Concrete experience* involves carrying out activities such as Assignment 4 (implementation of action plan). *Reflective observation*, the second stage of the cycle, entails participants taking a step back from the "doing", i.e. the group work and implementation of the action plan, and reviewing what has been done, how it went and why. Examples are Assignment 1 (identification of challenges based on previous experiences) and Assignment 2 (observation of challenge in practice). However, it is through *abstract conceptualisation* that students give meaning to these activities by relating them to the "bigger picture", such as content delivered through the online seminars and the tools, which also provide the arguments for their decisions and design of plan of action in Assignment 4. In the final stage of the learning cycle, *active experimentation*, the students considered what it is needed to address a given the challenge, what they have learned and how this will be put into practice. An example of active experimentation is the design of a plan of action in Assignment 4. After this stage, a new cycle takesplace.

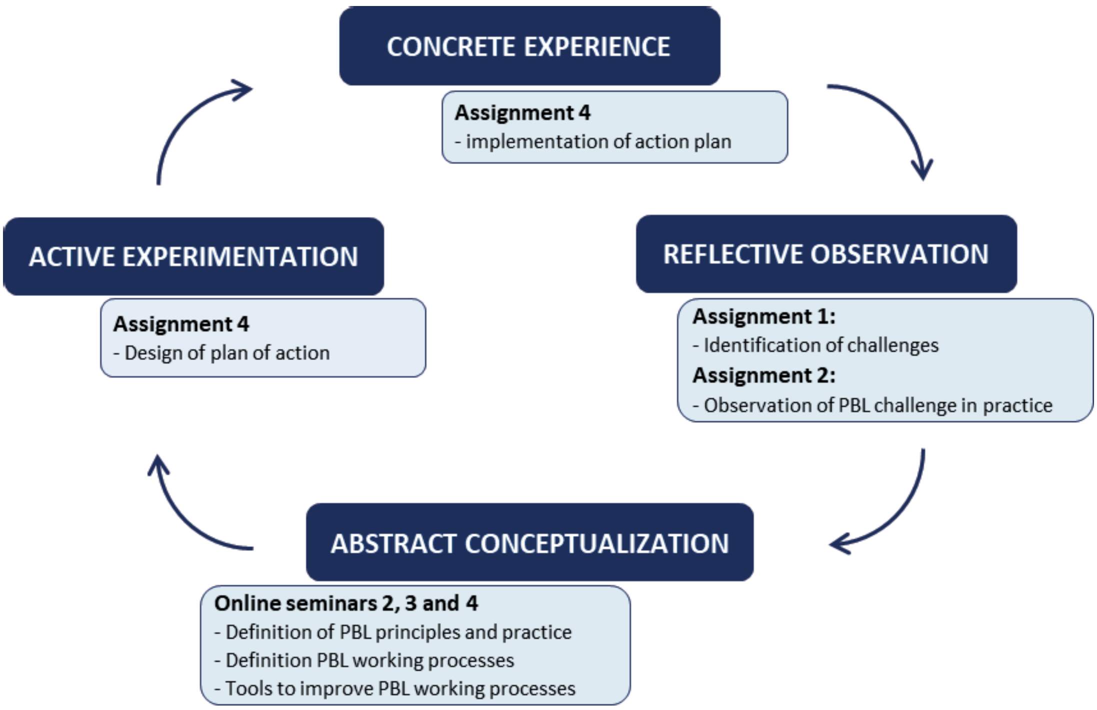

Figure 3. Relationships between Kolb's learning cycle and the online course activities.

4 Implementation and evaluation of online course "*PBL and Project Management*"

The online course was delivered from 11 September 2019 to 14 October 2019 to six students (i.e. total no. of students enrolled in the Master programme). The course uses Moodle *Extrac doc* (name given by university to the Moodle platform) as the learning management system (LMS) and *Lifesize* as the telecommunication application. *Lifesize* is used for online seminars, whilst *Extrac doc* is used to organise the course and as repository of resources. The online seminars were delivered synchronously, where students were together in a physical space (i.e. classroom at university) and the lecturer was online, using the telecommunication application. Three groups of two students carried the assignments out asynchronously, supported by resources and materials uploaded in the LMS. The communication between students and lecturer was done by email and in the discussion forum of the LMS. The course evaluation was conducted when the course finished.

The literature on PBL and distance learning (see for example, Graham, Cagiltay, & Craner, 2000; Hutchins, 2003; Savin-Baden, 2007) serves as precepts to develop the course evaluation model, which includes three main perspectives (Figure 4):

- Technological perspective (e.g. focus on digital tools and applications used, their functionality and usability),
- Instructional perspective (e.g. focus on structure, organisation, material, online resources and sessions of the course), and
- Learning perspective (focus on students' expectations as well as relevance and impact, content and assignments of the course).

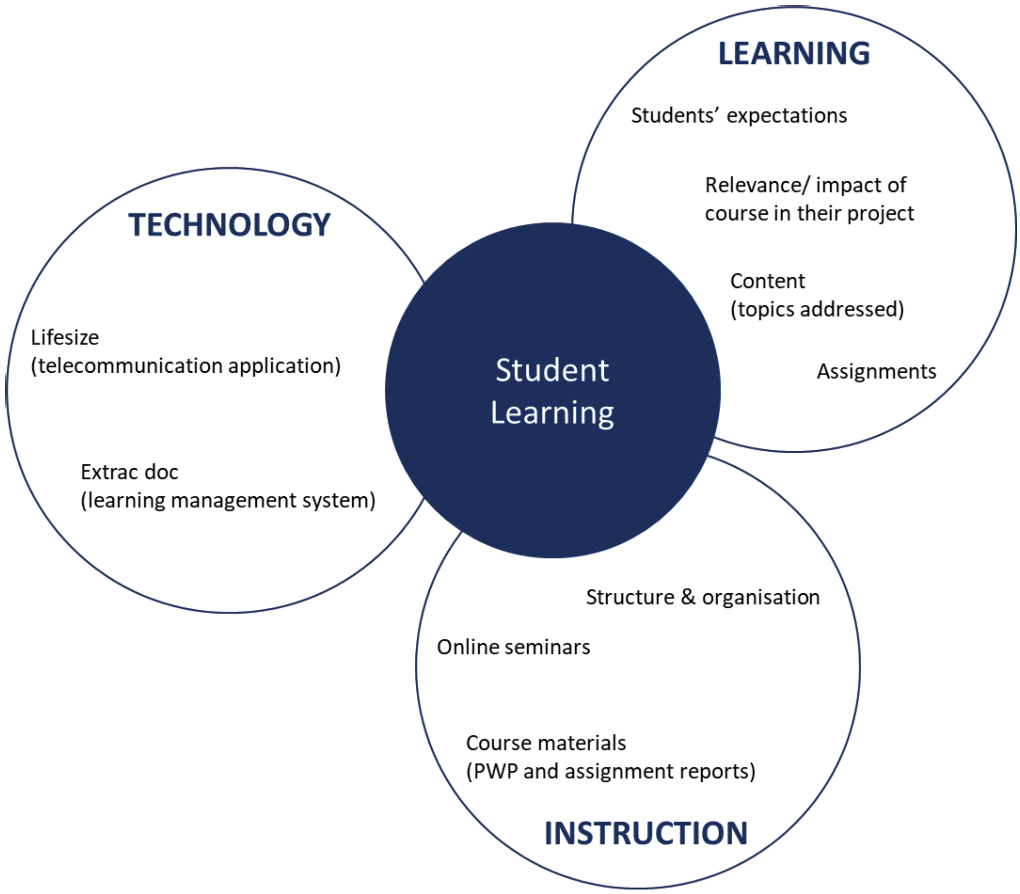

Figure 4. Three focus areas of evaluation and respective items.

Following the evaluation model, a questionnaire is constructed. Ten closed questions, with four-point scale, compose the questionnaire. Each closed question is followed by a text box for further comments. Besides these questions, the questionnaire also includes one last open question to gather students' suggestions for improvement (Table 4). The questionnaire was delivered using the LMS features, and only two out of six students have answered it.

Table 4. Evaluation perspectives and respective questions

Evaluation focus	Questions
Learning (closed questions)	• To what extent has the course met your expectations? • How do you evaluate the relevance of the course topics (i.e. problem orientation, collaboration, project management) in your learning and project work? • To what extent has the course structure (i.e. online seminars followed by group assignments) supported your learning. • How appropriate do you find the assignments to supporting your learning and project work? • To what extent do you consider that this course will affect your work in future projects?
Instruction (closed questions)	• How do you evaluate the way the online seminars were delivered and conducted? • How do you evaluate the seminars' slides and the assignment reports? • How do you evaluate the no. of sessions, temporal organisation and delivery of the course? • How do you evaluate the tools, links and literature provided in the course?
Technology (closed question)	• To what extent the technologies used have impacted your learning during the course?
Other (open question)	• What overall suggestions can you give for the improvement of the course?

Students' feedback

Both the number of students attending the course and answering the evaluation questionnaire are very low. For this reason, the evaluation information gathered through the questionnaire does not allow drawing solid conclusions about the course quality and fulfilment. Nevertheless, we have decided to include the evaluation results in this paper because we consider that it triggers reflections and points for further discussion. Table 5 shows students' answers to the questionnaire.

Table 5. Answers from students (*n*=2)

Evaluation focus	Question	Response
Learning	• To what extent has the course met your expectations?	(3) To a moderate extent; 2 (100%)
	• How do you evaluate the relevance of the course topics (i.e. problem orientation, collaboration, project management) in your learning and project work?	(3) Relevant; 2 (100%)
	• To what extent has the course structure (i.e. online seminars followed by group assignments) supported your learning?	(3) To a moderate extent; 1 (50%) (4) To a large extent; 1 (50%)
	• How appropriate do you find the assignments to supporting your learning and project work?	(2) Somewhat appropriate; 1 (50%) (4) Very appropriate; 1 (50%)
	• To what extent do you consider that this course will affect your work in future projects?	(3) To a moderate extent; 1 (50%) (4) To a large extent; 1 (50%)
Instruction	• How do you evaluate the way the online seminars were delivered and conducted?	(3) Good; 1 (50%) (4) Very good; 1 (50%)
	• How do you evaluate the seminars' slides and the assignment reports?	(2) Somewhat good; 1 (50%) (3) Good; 1 (50%)
	• How do you evaluate the no. of sessions, temporal organisation and delivery of the course?	(2) Somewhat good; 1 (50%) (3) Good; 1 (50%)
	• How do you evaluate the tools, links and literature provided in course?	(4) Very good; 2 (100%)
Technology	• To which extent have the technologies used impacted your learning during the course?	(3) To a moderate extent; 1 (50%) (4) To a large extent; 1 (50%)

Overall, both students evaluate the course as relevant, with appropriate structure and materials from a moderate to large extent (see Table 5). This indicates that the course fulfils its main goal in supporting student learning in a PBL environment, which is also highlighted by following student's statement:

> *"I think the course was **really relevant** and it has **planted the seeds in my mind to develop the approach throughout the next projects I will be part of**. It's a shame that we only had few sessions because I feel like **this is something that needs to 'develop' instead of simply 'learn'**."*

The above also refers to the short duration of the course, which means that students might need more than 15 hours to develop competences to manage their project and learning. One possible explanation is that PBL and project management are relatively new topics and out of the expected technical domain that characterises the traditional engineering education. This might mean that students need to adjust to different disciplinary domains and discourse that the innovative and PBL environment requires, namely interdisciplinary knowledge and collaboration. This requires time, which is partly corroborated in the following statement:

> *"If I can give you some kind of suggestions it would be to keep the quality of your sessions because you are a big plus to this course but **we need more time and experience to properly assimilate the concepts for years to come.**"*

Regarding the instruction perspective, students also consider it good to very good (see Table 5). However, a further comment suggests that more attention should be given to font size and amount of text put in the slides when making online presentations, especially when using a videoconference style. One aspect brought by students in the open question relates with "synchronism" between the course and project work. Note that the course runs in parallel with project work, and it is part of the project module. It started one week after the project starts however; a student considered that the course had a "fast pace" when comparing with the project. The consequence is that the assignments and what is expected to be delivered as part of the course and implemented in project work were not always clear, as the following statement highlighted:

> *"The pace of the course was **much faster than the pace of our projects** [...]*

In addition, the students' focus was in getting hold of what was expected from them and organising their project overall, including the time and physical spaces for group work, as the following statements highlighted:

> "*A part of explanation for these different paces is that here* ***we do not have any room and specific time to set meetings****. We have to organise that according to our different personal free time and we also need to find a place to work in small group (which is impossible in UniNantes)*".

> "*I also felt like it was too early in the development of this approach to give us projects that were entirely open because even if the first objective was to make us steer the project in a direction that we found to be the best, we were too much lost instead to do anything without thinking that we would probably waste our time on irrelevant matter*".

Aligning better expectations and "slowing down" (e.g. starting later than the project work starts; or increasing the time between online sessions) the pace of the course are two important points to consider, especially if it is needed to increase students' motivation in engagement in these type of courses.

Nevertheless, the technology used has a moderate to large impact on student learning. However, there was no elaboration on how and why from the students' side. These are two questions that should be further explored and deepened in future evaluations in order to understand the impact of technologies used in student learning with the aim to, for example, design better online learning experiences for students.

5 Final reflections

The paper describes a design and implementation of an online course on PBL and project management in the international engineering Master programme MAREENE. The curriculum is problem-oriented and project-organised. The PBL and Project Management online course integrates a two ECTS project module

per semester, and its overall aim is to equip students with knowledge and skills needed to manage their learning in a PBL curriculum. The online course ran between September 11 and October 14, 2019 for a total of six students. Its evaluation was voluntary, enabling to gather only two responses. Nevertheless, the results gathered show that the course fulfilled its overall goal and was relevant to student learning in a PBL environment. It also planted the seeds for the need for further experience and development for future projects. The evaluation and students' written responses to open questions also provided some more insights and raised aspects for further reflection and discussion when it comes to online courses to support student learning in a PBL environment, namely, the relevance of physical spaces as complementary to online courses (at least in the beginning), course duration and its alignment with project duration and phases, clarification of expectations and the impact of technologies on student learning. These could be also key perspectives for future development of online courses for students that also are part of a curriculum change process, i.e. change from a teacher-centred learning environment towards a more student-centred environment, such as PBL. In addition, the paper also describes the use PBL and distance- learning principles to design online courses (see for example, Table 3 and Figure 3). Independently of the content addressed in the online course, these can constitute guidelines to design student-centred, flexible, exemplary, problem-oriented online courses, where student learning and experiences are at the core.

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Sustainability, Complexity and Interdisciplinarity – Generating innovative and interdisciplinary knowledge and practice

A “PBL effect”? A longitudinal qualitative study of sustainability awareness and interest in PBL engineering students

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Abstract

The global sustainability crisis is growing by the year, and students are asking universities to increase sustainability contents in their curricula in response. The Education for Sustainability literature suggests that problem-based, interdisciplinary learning methods are well suited to imparting sustainability education. A recent quantitative study on engineering education supported this claim, showing that engineering students graduating from a systemic PBL university had increased sustainability awareness compared with graduates from other universities. But how does this awareness develop and manifest during the students’ education, and what is the role of PBL therein? Answering this question requires a qualitative approach and therefore, we followed 16 PBL students across four engineering disciplines (mechanical engineering, electronic engineering, environmental planning and medialogy) during three semesters using semi-structured interviews and an interpretivist framework. We asked students to reflect on their awareness and interest in sustainability issues, in their first month of study, the end of their first year, and the middle of their second year. We were able to gauge the changes in their sustainability awareness and interest during the process of acclimatisation within their engineering studies.

We found that in the first round of interviews, the majority of students, with the expected exception of environmental planning students, were marginally aware of sustainability issues and not very interested in the subject. By the end of the study, a notable shift towards overall increased awareness and interest was observed. In this paper we use the interview data to explain and categorize the changes. The results underpin and qualify a discussion of the role of PBL in fostering changes in awareness and interest in sustainability.

Keywords: Sustainability Education, Engineering Education, Longitudinal Study, Qualitative Research, Problem-based learning.

Type of contribution: PBL research paper

1 Introduction

The United Nations Sustainable Development Goals (UNSDGs) aim to tackle some of the world's most "wicked" problems, including the climate crisis, plastic pollution, biodiversity loss, and chemical pollution in the air and water. These problems are such that some scientists warn us that we are currently pushing the limits of planetary boundaries beyond which human life of the planet would not be sustainable (Rockström, et al., 2009). The awareness of the multiple sustainability crises and the necessity to educate the workforce of tomorrow to actively contribute to resolving them has become an important goal for change in higher education. In engineering education, diverse strategies are applied to that effect, ranging from add-ons to existing courses, integration into a more coherent curriculum, and systemic curriculum change (Kolmos, Hadgraft & Holgaard, 2016)

Education for Sustainable Development (ESD) scholars have been suggesting for decades that pedagogies that foster collaborative problem-solving are a key component of *sustainable education* (Sterling 2001). In Engineering education, several scholars have argued that one of the best ways to increase sustainability awareness and engagement amongst engineering students is through group projects that are problem-based (PBL) (Coral, 2009; Guerra, 2014).

A recent longitudinal study of engineering schools in Denmark indicated that when students entered engineering studies nationwide in 2010, there were no significant differences between the students from different institutions with regards to any of the specific sustainability variables measured (Kolmos & Holgaard, 2017). These included self-reported "readiness" with regards to contemporary issues, ethics, the global context, the societal context, environmental impact and social responsibility. However, by the 10th semester, a significantly higher percentage of students from a systemic PBL university (compared to other universities) assessed themselves to be very well prepared for tackling sustainability issues, and had increased confidence in the above-mentioned sustainability competences (Kolmos, Holgaard and Clausen, 2020). All of the Danish institutions included in this study displayed elements of PBL within their curriculum. But only one institution had a systemic approach. This means that PBL was done at the level of the curriculum throughout the whole institution, rather than piecemeal in a course-by-course basis (AAU, 2020). This includes a more explicit progression throughout the curriculum for both sets of competences. Key to the findings of this study is that the observed increase in sustainability competences between entry into and exit from the study programmes is reinforced within a *systemic* PBLenvironment.

What is difficult to gauge from the quantitative data of this survey, however, is how exactly the sustainability competences develop from a similar baseline across all Danish engineering universities at the beginning, to marked differences in favour of the project PBL approach at the end. It is therefore necessary to take a magnifying glass to the experience of engineering students within the PBL system and find out how their awareness of and interest in sustainability evolve as they immerse themselves in their studies. Such an approach is best fulfilled through qualitative research methods in a longitudinal study, within the bounds of a carefully restricted time period to avoid losing the richness of the detail in overwhelming amounts of data.

As an exploratory approach, we suggest it would be interesting to look at the period in which students *acclimatise* to the PBL system throughout the first three semesters following the research question:

What are the patterns of change in students' awareness of and interest in sustainability issues during the process of acclimatisation to their engineering studies. Do we see differences across different engineering programmes?

2 Literature Review

2.1 Background

In this paper, we aim to present different patterns of change for students' development of sustainability awareness and interest during the process of acclimatisation within their engineering studies. This will help us to create a frame of reference for supporting engineering education for sustainability, and raises important concerns about the role of engineering education in the push for sustainable development. As noted by Svanstöm (2018:36):

> *First, it is perhaps important to mention the elephant in the room - should behavioural change be a goal of education? To discuss this, it first needs to be established what behaviour is considered. It is uncontroversial that we want students of engineering to adopt appropriate behaviour with regard to the profession and the different situations that may appear, for example to behave in a safe way in the laboratory and to behave towards collaborators and other people in an ethical manner. However, when it comes to the personal sphere, it might be considered controversial to aim for behavioural change, at least in higher education. Arguments against such approaches would be that they are normative and instrumental and that they therefore clash with ideals of 'Bildung' in universitystudies.*

In pointing to the "elephant in the room", this quote highlights the tension between the personal (private) and the social (public) formation processes within higher education, and the potential clashes that this creates between ideals of a more theoretically-oriented '*Bildung*' tradition on the one hand, and imperatives of behaviour change for sustainability on the other. It seems that, taking into consideration the urgency of addressing the sustainability crises, taming the elephant in the room might become a question of redefining the ideal of '*Bildung*'.

Lange (2004) suggests that one way to do this is through the use of dialectics, in particular through the importance of a dialectic relationship between transformative and restorative learning. He argues that these two types of learning together constitute the pedagogical basis for sustainability education, which can revitalise citizen action. Whereas restorative learning adds stability by providing insights into, or at least interpretations of, dominant cultural scripts; critical transformative learning attempts to foster an individual's consciousness of himself or herself as situated within a larger societal context. Therefore, adding sustainability perspectives to an engineering curriculum not only adds introspection into one's own role in sustainable development, it also increases the complexity of one's socialsphere.

To address this complexity, several scholars in engineering education for sustainability have called for system-thinking (e.g. Dowling et al., 2009) and trans-disciplinarity (e.g. Byrne & Mullally, 2016). In engineering education for sustainability, this is related to the increasingly distributed innovation process, the increasing complexity of technological systems as well as the complexity of the sustainability challenge as outlined by the UNSDGs (UNESCO, 2017).

2.2 Sustainability competences and engineering education

A recent UNESCO report (Riekman, 2017) emphasizes new types of sustainability competences cutting across the SDGs as an important learning outcome for students to achieve:

1. System-thinking, critical thinking and strategic competences which are based on knowledge of the field;
2. Integrated problem-solving and collaboration competences which are based on knowledge and skills.

3. Anticipatory, normative, and self-awareness competences which are all competences based on a combination of knowledge, skills and personal awareness.

According to the US accreditation unit for engineering programmes, ABET, engineering students need "*the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*" (ABET, 2017: 5).

Based on a comprehensive study of 10 engineering education institutions, Coral (2009) concludes that problem-solving prepares students to be responsible, which is likely to require introspection about their values, ethics and beliefs. Furthermore, Coral (2009) concludes that project-based learning linked to real transdisciplinary projects is the most adequate pedagogy to learn sustainability competences. Other studies (e.g. Guerra, 2014) conclude in a comparable way that problem and project based learning can be seen as a promising strategy in terms of embracing the personal (introspection, responsibility, agency – linked to competency 3 above) as well as the social (distributed, real-world, transdisciplinary – linked to competences 1 & 2 above) aspects of sustainability.

Taking the above into consideration, we aim to broaden the study of students' awareness and interest to work from the assumption that the dialectic relationship between the personal (private) and the social (public) spheres play an important role in defining patterns of change in students' awareness and interest. Furthermore, as problem and project based learning is highlighted as a promising approach for education for sustainability, we will study these patterns of change in an institutional case founded on this approach.

3 Methodology

Given the existence of prior quantitative surveys on the subject, this paper use a qualitative *thematic analysis* approach (Braun & Clarke, 2012), characterised by relatively small sample sizes (between 10 – 30 participants), rich data analysis and a focus on transferability rather than generalizability. Given how little has been written on the subject, we chose an inductivist approach to theme construction rather than a theory-driven one, meaning that the themes emerge from the data rather than from a pre-determined theoretical framework. We operate within a social-constructivist epistemology, meaning that we are not looking for "objective" descriptions of social phenomena with *essential* qualities, but for the ways in which participants *construct* meanings and understand their place within social phenomena whose interpretation is subjective to participants and researchers alike (Bailey & Douglas, 2014).

3.1 Participants

As with most qualitative studies, we used purposive sampling to gather participants (Etikan, 2016). We specifically looked for participants from three different types of engineering studies: "classical" engineering, for which we contacted students from electronic engineering and mechanical engineering, tech-oriented engineering, for which we contacted students in a computer science and design programme called *medialogy*, and more "soft" sustainability-oriented engineering, for which we contacted the students from a planning programme in environmental management (BEM). Within those categories, we recruited male and female participants, in proportions which reflect roughly the proportions within the student population. We therefore had only had one female participant in the "classical" engineering category, one in the "tech-engineering" category, whereas the majority of the participants in the BEM programme were female. We were looking to recruit between 7-10 participants in each engineering programme, but due to the time-consuming nature of qualitative interviews, 6 participants signed up in each programme, and two dropped out in between the first and second interview in mechanical engineering and BEM, bringing the total number of participants to 16 over the entire study.

Table 1: Participants in the longitudinal sustainability study. Grouped per engineering degree programme

Student	Age (at the start)	Gender	Degree Programme
EE.1F	19	Female	Electronic Engineering
EE.2M	33	Male	Electronic Engineering
EE.3M	23	Male	Electronic Engineering
ME.1M	32	Male	Mechanical Engineering
ME.2M	29	Male	Mechanical Engineering
ML.1M	19	Male	Medialogy
ML.2.F	22	Female	Medialogy
ML.3M	20	Male	Medialogy
ML.4M	22	Male	Medialogy
ML.5M	19	Male	Medialogy
ML.6M	19	Male	Medialogy
BEM.1F	21	Female	Bachelor Environmental Management
BEM.2M	18	Male	Bachelor Environmental Management
BEM.3F	21	Female	Bachelor Environmental Management
BEM.4F	20	Female	Bachelor Environmental Management
BEM.5F	22	Female	Bachelor Environmental Management

3.2 Interviews

The participants were informed by email of what the study was about, provided with a slide deck explaining the purpose of the study, the number of interviews they were expected to attend, the approximate duration of the interviews, and how the data would be handled. They were asked for their consent to record the interview and use the data anonymously for research purposes before each interview, and agreed on record. There were three rounds of interviews: one round at the beginning of the bachelor programme during the introductory PBL project period known as P0, one round after students completed their first fully fledged project, in the beginning of the PBL project period known as P2, and a final round at the end of P3, by which point students are considered to be "acclimatised" to their PBL studies. The questions of the final round were sent in advance to the students to provide them with some time for reflection. We noted that this increased the quality of the answers.

Table 2: Interview rounds and structure

Interview Round	Interview Structure	Question themes
R1 (Start P0)	Semi-structured, same structure for all students. Questions not sent in advance.	Personal history; Reasons for choosing engineering; Sustainability awareness and interest; Sustainability actions
R2 (Start P2)	Unstructured, following on from answers from R1. Questions not sent in advance.	Students asked to reflect on previous responses, and anonymous responses of others.
R3 (End P3)	Semi-structured, but structure is personalised for each student	Sustainability awareness and interest [If increased, reasons for increase] Sustainability actions

	based on previous answers. Questions sent in advance.	[Reasons behind (in)actions] Reflections on relationship between students' specific field of engineering and sustainability Future perspectives on sustainability

3.3 Analysis

Unlike phenomenological or phenomenographic work, thematic analysis does not require verbatim transcripts, so the researchers listened through the audio recordings of the interviews several times. The first time, no notes were taken so that a full picture could form in the researchers' head. The second time, the researchers noted down all the key points and interesting quotes in the interviews, then transferred this into a spreadsheet in a 3 x 16 matrix where all of the interview notes could be compared across participants, and across the rounds of interviews. The interview notes where then organised thematically in response to the research question. We classified the student responses into four thematic categories that form "levels" of awareness and interest.

4 Data Analysis

If we define awareness as *knowledge and understanding* of the sustainability crises, and interest as *the propensity to seek out information about the sustainability crises*, we see that students fall into four basic categories of awareness and interest.

4.1 Category 1: no interest, little general awareness

The first category indicates that students express no interest and very little knowledge or understanding of sustainability issues. For instance, **ML.6M** said:

> ***ML.6M R2:*** *I know it's a thing, but I don't know what to do about it… well, it's partly my own fault because I haven't looked up what I could do about it, but I don't know, if the world… this global warming, I don't know what I could do to help… ignorance is bliss.*

There were three rationales offered for this lack of interest and awareness, the first, as exemplified by ML.4M, is that the sustainability crisis is too frightening and calls upon such changes in attitudes and behaviours that it is better not to know and not to deal with it:

> ***ML.4M R1***: *I think we did a project once [in high school] about some environmental stuff, and it was scary… [it made me feel] sad and worried, I'm afraid for the next generation.*

The second, as exemplified by ML.2F, is that the students are devoting so much cognitive bandwidth to their studies that they don't have time or energy to get informed about sustainabilityissues:

> ***ML.2F R2***: *I think I'm much less considerate to things happening outside my studies because it takes up all the space.*

The third, shown by EE.3M, is that personal issues mean that the students are more focused on their immediate worries than about global problems:

> ***EE.3M R1:*** *I don't really know what I would do if, like, my house was submerged in water and things. I mean it's not really things that I worry about daily. I have other things to worry about, like how do I survive the end of the month.*

The fourth is that in the absence of obvious strategies to solve the sustainability problem, students would prefer not to know too much or worry too much about it, as exemplified by **ME.1M**:

> ***ME.1M R1:*** *I, pfff, I haven't really given it much thought, and I don't… I try not to interfere with stuff that's out of my reach.*

4.2 Category 2: little interest, basic general awareness

The second category indicates that students show a little bit of interest in sustainability issues, usually triggered by postings on social media, and are curious enough to read up on the basics, as such being aware of issues like the climate crisis and plastic pollution, some of the basic drivers of those issues like eating meat, flying, consumption culture etc., and that these issues are getting worse. However, this basic knowledge often seems to trigger feelings of cognitive dissonance that comes with this basic knowledge, as exemplified by **ML.3M:**

> ***ML.3M R2*****:** *I know about the effects that the meat industry has on a global scale, but I would never really consider becoming a vegetarian because I like the taste of meat... I think it's part of a healthy diet and all the like, and perhaps it's also a bit of… you kind of feel entitled to that, after this many years of evolution, we have climbed our way to the top of the food chain, we have opposable thumbs, we deserve to eat meat.*

Cognitive dissonance can be defined as an attempt to reconcile incompatible beliefs and actions, and is a common reaction to increased sustainability awareness (Stoll-Kleeman et al, 2001) In this case, believing the meat industry is a sustainability problem, but continuing to eat meat. As shown in this quote, one strategy to resolve cognitive dissonance is to provide mitigation to the belief system to make it "fit" with the actions – in this instance, a moral justification for eating meat, "we deserve it". Another reaction to this level of basic awareness is conflicted emotional feelings, and technological escapism – the idea that we can escape to Mars was particularly prominent in the medialogy and classical engineering groups, as exemplified by**EE.1F**:

> ***EE.1F R2****: I've been in this denial thing, "oh this will affect my children, my grandchildren", but then I've learned that it is happening now so it is affecting me, so I've gone to "I sort my plastic, I sort the waste and I don't use plastic straws and all that stuff". It's not enough to make it OK. Just because I do it. So, I'm also a bit in despair, well, we're kinda screwed, let's go to Mars!*

4.3 Category 3: basic interest, basic general awareness and advanced domain-specific awareness

The third category shows that students have a basic interest in sustainability issues, meaning that they are sufficiently driven by the issue to read news on the subject, to pick up on the issue when it is raised in their studies, and to involve the issue in their PBL projects. As such, while they have a good basic awareness of the major sustainability crises, they also have some advanced domain-specific awareness.

One of the principal drivers for increased interest in sustainability issues up until this level seems to be the prominence of sustainability issues in mainstream media, and in particular the media presence of the Swedish climate activist Greta Thunberg, and the American green tech-entrepreneur Elon Musk as explained by **EE.2M** and **ME.2M**.

> ***EE.2M R3:*** *I think it's great to have someone with a network like Greta Thunberg has got now. The network she has built, the organisation around her, it moves something, especially when she… like, the Nordic Council, just refused to take an award, so in that way I think it's great.*
>
> ***ME.2M R2:*** *Maybe I'm listening too much to Elon Musk. He thinks we can solve all the world's problems by shooting rockets to Mars.*

The result is a good general knowledge base on the sustainability crisis, as an interest in finding out more. Interestingly, for some students, the presence of these "media heroes" generated paradoxical reactions, on the one hand getting them more interested in the subject, but on the other leading them to vehemently disagree with the solutions offered by these public figures, as exemplified by **BEM.2M** and **EE.3M**:

> ***BEM.2M R3***: [*Me and my fellow students] are more likely to do their own research or express motives or incentives on the basis of actual peer reviewed articles, rather than sources or information through these propagandist "nonviolent civil disobedience" environmental movements "Extinction Rebellion", "Greenpeace" or Danish "Den Grønne Studenterbevægelse".*

It should be noted that this student disliked the sustainability attitude and modes of engagement of BEM students so much that he switched to the environmental sciences programme instead after P2, and these new classmates are who he refers to when he refers to his "fellow students".

> ***EE.3M R3:*** *I thought a lot about people like Greta Thunberg and Alexandra Ocasio-Cortez, that came up with the Green New Deal, and I don't agree with their approaches. I do believe in climate change and it's an important issue but the way they do it, I simply don't agree… I still have hope that we can find a technological solution.*

In this category, there is also specific, in depth knowledge and interest in one or several particular domains. Usually, this specific interest appears to be triggered by an interesting PBL project on a relevant sustainability subject, or a class on sustainability within the curriculum, a situation encountered by **ME.1M** and**ML.2F**.

> ***ME.1M R3***: *We had a lot on the mechanical properties of plastics, we had a lot on microplastics - the lecture definitely was an eye opener for me. I'm definitely thinking about it more than I used to.*

> ***ML.2F R3:*** *In the 2nd semester we had the options of working with exercise or food waste, and I was very excited about working with food waste and I actually got to do that and that sparked an interest in how I could continue to work with these things.*

4.4 Category 4: high interest, advanced "systemic" awareness

The fourth category covers students who are actively interested in sustainability issues, and actively try to integrate these issues in their studies and as part of their lives – this relates to the competences identified in the literature review (Riekman, 2017). These students show a good understanding of the scale and scope of sustainability problems, and have both broad and deep awareness of major sustainability problems. It could be said that they have a "systemic" awareness because they are aware of the systemic problems that cause systemic sustainability issues. Almost all the students who have this level of interest and awareness were already interested and aware at the start of their degree programme, but pushed it further during their degree programme. This level of awareness correlated strongly, but not always, with political engagement, as we shall see.

> ***ML.1M R3:*** *I've realised how much of a huge deal it is, it's bigger than all of us…. When I saw how close we are, that we have a deadline, by 2040, we need to change. And that kind of woke me up, like, yeah, this is really messed up. We're killing ourselves! We need to change quick.*

> ***BEM.3F R2***: *There still needs a lot of things being done with sustainability… there's a lot of individual people, or small groups, especially with plastic or with how you need to stop using plastic straws or something, there's a lot of small, individual groups of people saying – "this is bad", or making reusable straws, or, yeah, a lot of small groups doing that, but it's not only the plastic straws that need to be dealt with, it's the whole plastic industry.*

The systemic awareness was most prominent in the BEM group, and BEM.5F credited the study programme for this:

> ***BEM.5F R2:*** *I think there's a lot in my personal life, but also, I think also the studies because you read about all these things that are being done and the possibilities on what more can be done, and that motivates you.*

But there was most probably also a selection-bias at the start of the programme, as we know that students who are already aware and interested in sustainability are much more likely to opt for environmentally-oriented studies, as described by Prevot, Clayton and Mathevet (2016).

5 Discussion

In terms of the evolution of the responses over time, we see clearly in Figure 1 that the classical engineering students and the medialogy students start at a different level of awareness and interest than the BEM students, which can be attributed to the above-mentioned selection bias. We see an increase in awareness in the vast majority of students between R1 and R3, regardless of their starting position. Four students did not change their awareness and interest levels.

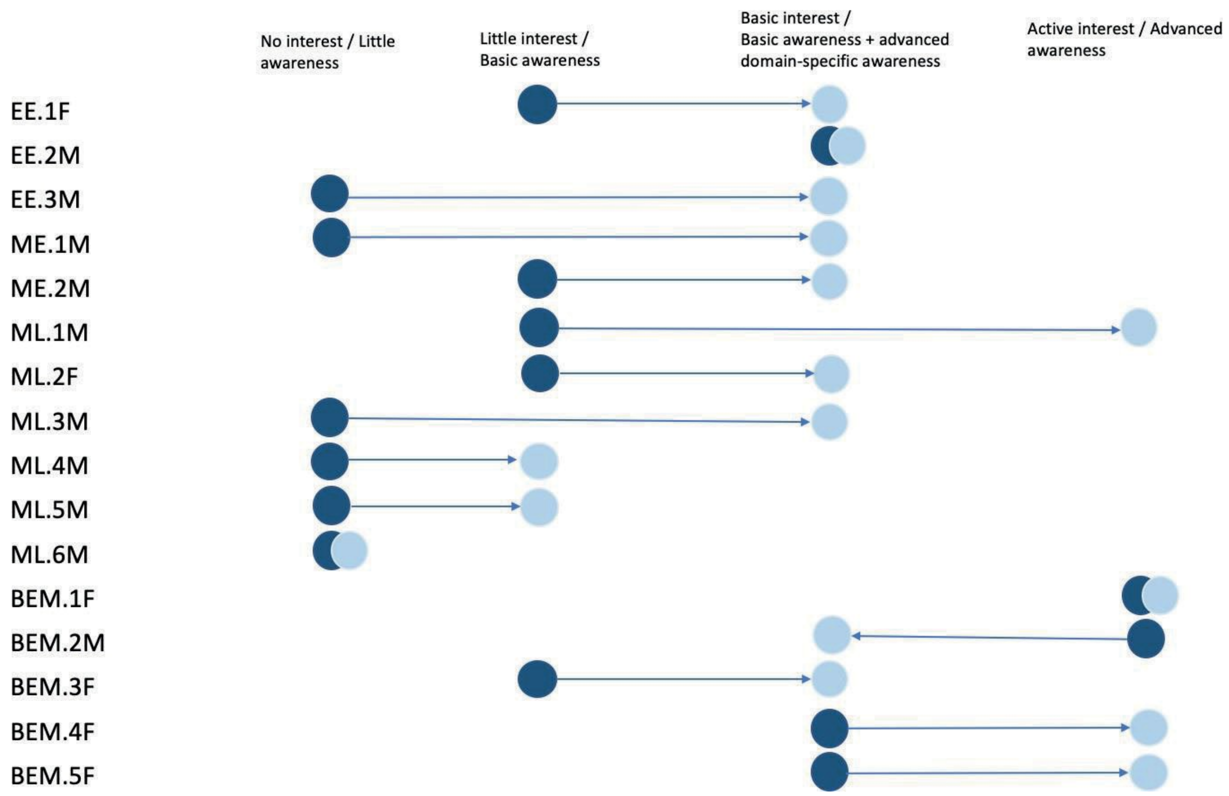

Figure 1. Evolution of sustainability interest and awareness between R1 and R3

We can propose the following explanations for the exceptions:

- ML.6M is truly afraid to delve into the subject and lives by his motto than “ignorance is bliss”. His own powerlessness in the face of the sustainability crisis terrifies him and he would rather not know at all, than knowing, and then needing time to build up sustainability competences to address his anxiety.
- EE.2M was already fairly aware of the situation, but any further interest was limited by personal mental health struggles, and he found the subject too depressing to go further.
- BEM.1F she was already extremely aware and involved at the start of the programme, and while her engagement levels changed (she joined Extinction Rebellion), her awareness and interest remained high.
- Student BEM.2M became less systemically aware of the situation, going from a situation of systemic awareness and interest, to one in which he only focused on one specific domain, namely energy, and

only from the standpoint of theoretical physics. This could be explained by his negative interactions with his BEM project group, prompting him to leave the BEM programme altogether.

The overall shift in awareness and interest seems to have two main causes, as mentioned above:

- firstly, the increased media attention given to sustainability issues, particularly in the wake of actions by Greta Thunberg, Extinction Rebellion, and Elon Musk, among other "big names" in the sustainability debate. This is in line with what has been called in the mainstream media a "Greta-effect" (Nevett, 2019), according to which the Fridays for Future movement led by the Swedish teenager has spurred a world-wide increase in awareness and interest in sustainability among young people.
- Secondly, the introduction of sustainability issues within the courses and projects. It was however no clear whether the specific PBL project format had any advantage over regular lectures in introducing students to sustainability issues since both were mentioned by students as factors triggering interest. It may be, however, that the PBL format indirectly increases students' interest in global problems, and the "real world" nature of the project problems encourages domain-specific awareness. Thus, while the previous quantitative study and this qualitative study present circumstantial evidence for a "PBL-effect", it might be suggested that more fine-grained qualitative approaches such as case-study or diary studies, which include direct observation of the PBL work and in-the-moment reflection would provide further insights that post-hoc qualitative interviews.

While our results show that an increase in sustainability awareness and interest is *likely* in a PBL environment, it is not guaranteed. Therefore, we suggest that there is a need for both targeted and systematic initiatives to increase the impact of education for sustainability in the curriculum for all students, even those that might be less susceptible to the methods currently employed. To do this, the project format is a promising format, but should be reviewed and improved in the light of emergent EESD innovations – for instance project types have emerged to promote a comprehensive systemic approach: so-called "mega projects", that have the ambition of engaging several student groups from different disciplines to address wicked sustainability problems.

6 Conclusion

This qualitative study presented further evidence to support the argument that engineering students in systemic PBL universities are likely to increase their awareness and interest in sustainability issues over the course of their degree programme. This seems to be the case across very different engineering disciplines, adding further evidence to the argument that this is not a phenomenon only confined to "environmental" engineering studies, but perhaps related to the PBL process itself as students orient themselves in the world outside academia through their projects. However, the precise effect of the PBL was not widely apparent from the interviews, and therefore it will remain as an argued hypothesis that project work adds sustainability awareness and interest via the problems analysed by the students within academic knowledge domains. Further research to investigate this could include diary studies during project work and field work observations of project work.

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Project Types and Complex Problem-Solving Competencies: Towards a Conceptual Framework

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Abstract

Project management and collaboration are considered core competencies in engineering education, both in relation to complex problem-solving and as part of the required professional skill set. The most common way of learning both project management and collaboration skills is by introducing different types of team-based projects in the engineering curriculum and letting students reflect on their skills development. However, the student experiencing and learning during a project process depends on the team size and duration of the project work, as well as the scope and organization of the project itself, ranging from a narrower disciplinary approach to a more contextual one, incorporating interdisciplinary and inter-organizational learning outcomes.

In this paper, we present a conceptual framework for understanding the variations in educational projects and intended learning outcomes for project management and teamwork. The project typology is based on two dimensions: 1) the scientific content and problem scoping, ranging from simple and complicated problems to complex and interdisciplinary problems; and 2) the size and organization of the team(s) implicitly involving project management processes on varying levels. Combining these two dimensions results in four educational project categories: the discipline project and multi-projects, addressing single discipline learning objectives on a scale from individual discipline teams to larger team clusters; and interdisciplinary projects and megaprojects, which cover contextual, complex and interdisciplinary learning outcomes on a scale from smaller interdisciplinary teams to larger 'teams of teams', or clusters in collaborative networks. These four ideal types of project frame students' learning of various complex problem-solving competencies such as problem identification, analysis and solving, collaboration skills and project management in different ways, all relevant in engineering education. Here, we focus specifically on intended learning outcomes related to the different types of interdisciplinary projects.

Keywords: project types, complex problem-solving, interdisciplinarity, problem based learning

Type of contribution: PBL conceptual paper

1 Introduction

Complex problem-solving competency is a relatively new requirement for engineering education, becoming increasingly distinct in the accreditation criteria in the past ten years (Accreditation Board for Engineering and Technology (ABET), 2014). Here, complexity is defined as a dynamic situation characterized by interdependent variables. Therefore, establishing a system overview is a requirement to be able to identify interconnections, dependencies and boundaries, which is a complex process involving many different factors. It is an instance of knowing neither the problem nor its solution (Snowden and Boone, 2007). For complex problem-solving, there is also a demand for actors to be able to handle complexity, and since engineers are considered one of the main human resources in any technological complexity, this becomes a requirement in the engineering profession (Attri 2018). A study of problems in the workplace indicates clearly that complex and ill-structured problems are the most typical engineering problems. These problems have multiple and often conflicting goals. They, can point to many different types of solutions and success criteria and constraints are often outside the technical domain (Jonassen et al., 2006). "*Complexity of a problem manifests itself in a number of forms, including the breadth of knowledge required, the difficulty level of comprehending and applying the concepts involved, the skill and knowledge levels required to solve the problem, and the degree of nonlinearity of the relations among the variables within the problem space."* (Jonassen and Hung, 2015:page 9). The more complex and boundary-less a given situation is, the more options can be generated – and especially when dealing with real world problems, the complexity extends beyond scholastic problem-solving skills (Dörner and Funkt, 2017).

In the Problem Based Learning (PBL) model at Aalborg University, complex problem-solving is considered an integrated and essential PBL competency (Holgaard, Søndergaard, & Kolmos, 2019). However, not all PBL practices address complex problems and a more variated project-oriented curriculum is needed to include complex problem-solving. Therefore, it is important to conceptualise various project types.

The term 'PBL competencies' covers four overall categories of competency; problem-oriented, project-oriented, team-oriented and metacognitive competencies, to reflect and further develop other more domain- or discipline specific competencies. These competencies are embedded within the curriculum, and students are required to reflect continuously on them throughout their education. The four types of competency are deeply interrelated. For one thing, different types of problem call for different types of project with different team constellations. As a consequence of the increasing need for complex problem-solving, there is a need to increase diversity in the types of project that students work on. It is not enough to let engineering students focus on parts of complex systems; they also have to capture the interconnectivity and dependencies of complex systems to address wicked problems. It is not enough to work with projects from within a discipline, as complex problem-solving most often calls for interdisciplinary synergy. Therefore, diversity and variation in the project experiences is fundamental for developing PBL competencies (Fraser, Allison, Coombes, Case, & Linder, 2006; Pang, 2003).

A recent review of PBL in engineering education indicates that the most common application of projects is within existing courses rather than across courses or at curriculum level (Chen, Kolmos, & Du, 2020). In this review, the majority of the research reports single course project activities, whereas only a quarter of the papers report a more systemic approach to project activities across courses or at curriculum level. At course level, projects are mostly applied as means for students to deepen their understanding of the lectures and to enhance students' motivation for learning. The project types reported in the literature review are characterized by problems mostly given by teachers, with few possibilities for the students to identify problems themselves, with a duration of about a semester as long as the course is running, and with smaller teams of mostly three to eight students (Chen et al., 2020). Reviewing the development from 2000 to 2019, the trend is an increase in the prevalence of project activities and students' project participation increasingly becoming the norm rather than the exception in engineering programmes. However, if students experience the same types of project process throughout the educational programme, there is a risk that it becomes routine, without any deeper reflection (Kolmos, 1999) and team collaboration becomes a type of tacit knowledge or a set of non-verbal action skills, where action is not necessarily based on discussion and knowledge sharing. Although the sharing of tacit knowledge through collaboration may provide expertise otherwise difficult to obtain, non-verbal expertise might be less transferable to other situations, since the learning is created and tied to a certain situation. For the experienced expert, according to Dreyfus and tacit knowledge and intuition will be at the highest level. However, the students are in a learning situation, and it is crucial that this experience and learning is reflected and conceptualized in order for it to be reconstructed in new situations. Experiencing variation and articulating contrasts, similarities and differences is one way to encourage reflection and make tacit knowledge and collaboration explicit. Therefore, we argue that it is important that students experience variation in the type of problems and projects they participate in to break routine and to make explicit tacit knowledge and competencies. In a PBL curriculum, this variation could include:

- Problem type (ranging from simple problems to complex problems)
- Project type (ranging from narrow discipline projects to complex megaprojects)
    - Project scope varying from few credits to many credits
    - Project length varying from shorter to longer courses, from one semester to x years
- Teams and collaboration
    - Group size varying from smaller to larger groups and teams in networks
    - Group composition varying from local to international teams
    - Group formation varying from student-initiated to teacher-initiated or theory-based
    - Types of collaboration varying from specific division of labour to integrated collaboration
- Facilitation
    - Relationship between lectures and projects
    - Supervision and collaboration forms
    - External collaborators varying from external project cases to project partners
- Variation in physical and digital facilities and learning spaces

Reflection on variation is an important source for learning how to carry out problem analysis and problem definition in a professional way, and not least for learning process skills to be able to enter into and handle problem-based project collaboration—in other words, PBL competencies. Through reflection on variation, the learner becomes aware of the characteristics of the experience and its relation to other educational experiences. For instance, if a student has experience with project management only in a single discipline group, that is the experience and knowledge this student carries, whereas having experience with two or three different types of group collaboration will most likely increase the ability to be flexible and adaptable to new situations (Pang, 2003). Although there are many ways to create variation in a curriculum, in this paper we focus specifically on the structural components of projects by focusing on problems and teams.

2 Types of Projects: The Problem and Team Dimensions

A project is defined as a unique endeavour with a specific goal to solve problems, which can be divided into sub-tasks. Projects range from small teams to hundreds of people depending on the issues to be solved and the defined tasks (Algreen-Ussing & Fruensgaard, 2006). However, in many engineering curricula, students are not offered the opportunity to reflect on variation, since the types of project students are working on are similar in terms of both scientific approach and team size, two important dimensions for scaling up and expanding projects. Scaling up the scientific approach concerns expanding the range of project types from single disciplines to interdisciplinary projects, in principle determining choice of discipline and method to match a similar range from narrow discipline problems to complex problems.

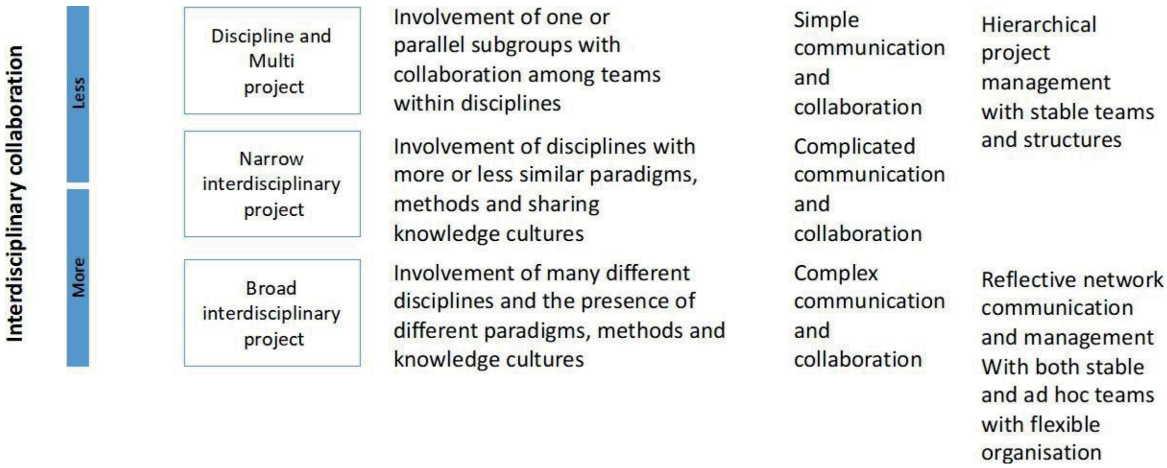

Figure 1: Types of interdisciplinary projects

The terms 'multidisciplinarity' and 'interdisciplinarity' are often used interchangeably in the literature. However, to understand variations in collaboration and complexity, we can benefit from a distinction between multidisciplinarity, understood as the cooperation of disciplines applied in parallel to a particular problem, and interdisciplinarity understood as the integration of discipline specific knowledge into one common project or solution (Klein, 2010; Szostak, 2004). Particularly within engineering education, interdisciplinary problem-solving will often result in a common product, and while the degree to which each discipline is integrated into the product will vary, all elements of the product will have to be adjusted to one other, which is considered a specific type of integration.

As illustrated in Fig. 1, another beneficial distinction can be made between narrow and broad interdisciplinary collaboration (Klein, 2006, 2010). Narrow interdisciplinarity covers collaboration within a shared knowledge paradigm with similar methods, while broad interdisciplinarity refers to collaboration across knowledge paradigms and scientific approaches. Within a narrow interdisciplinary team (such as chemistry, chemical engineering or biotechnology) a shared basic understanding of common methodologies, methods and data is more likely compared to a broad interdisciplinary team across e.g. humanities, social science and engineering with a larger variety of knowledge paradigms and thus increased complexity in the understanding, dialogue and negotiation of problems and problem-solving approaches. While collaboration and organization in any team, interdisciplinary or not, may bring conflicts and issues, a team collaborating across disciplines, compared to collaboration in teams with members from within the same discipline, is more likely to encounter difficulties in relation to understanding differences—e.g. in scientific paradigms and methodologies— and thus approaches to problem analysis and problem-solving. Furthermore, when the collaboration is of a considerable size (e.g. in 'teams of teams'), this can create challenges in how to organize work and collaboration across distance and time zones.

The team dimension refers to the number of students in one project. Smaller teams are usually considered easier to manage than bigger teams with more students. However, the type of discipline specific and interdisciplinary approach might add to the complexity of the project management and collaborative dimensions of the project regardless of how many students are involved in a project. Within traditional course structures, where the single discipline project is most common, the team size is usually about three to eight students working on a simple, single discipline problem in a project. For interdisciplinary projects, the number of team members will most likely increase, requiring the team (e.g. of eight to ten people) to reorganize in smaller sub-teams with specific parallel tasks and internal management processes both within and across all sub-teams working on the same project, making it a different learning experience compared to a single group working on a single-discipline problem.

2.1 Project Variations

Within the two dimensions, interdisciplinarity and team size, four basic project types can be identified; the *single discipline project*, the *multi-project*, the *interdisciplinary project* and the *megaproject*. This distinction of four project types is made for prescriptive purposes: real-life practice would provide more variations.

The *single discipline project*, usually carried out in a single project group, is well known and the most widely used both at course and curriculum level, where students within the same educational programme apply knowledge, theories and concepts to a simple discipline specific problem. An example can be a group of students applying control theory while developing an anti-sway system for a ship to shore crane.

The *multi-project* is less common and occurs in bigger courses or clusters of sub-disciplinary courses, and is characterized by a number of project groups working on the same or complementary elements (work packages) within the same or similar disciplines— e.g. in software development, or when groups work in parallel on the optimization of prototypes. These types of projects emphasise coordination among project teams to ensure the quality and feasibility of the common product and/or problem-solving methods. An example is computer science students optimizing an app for children with autism (AAU multi-project, 2020).

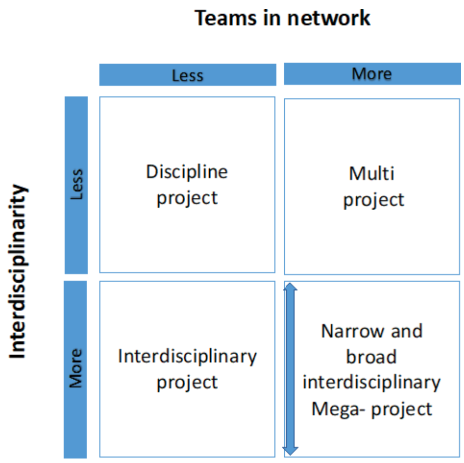

Figure 2: Ideal types of projects

The *interdisciplinary* project can be carried out in one project group of minor size. The team can be composed of students from different disciplines but can also be students from the same programme taking on an interdisciplinary approach to a particular problem or which is supported by a team of interdisciplinary staff members. For instance, in engineering projects, the preliminary problem analyses are often interdisciplinary in terms of academic scope, as students use e.g. sociological methods or participatory action research to identify user needs, allowing interdisciplinary knowledge to be integrated into a project with students from the same educational programme. An example can be students for media technology designing a sustainable city game for primary school, for which they need to have knowledge of both learning in primary shool, sustainable cities and game design.

The *megaproject* has recently been introduced into engineering education as something new (AAU, 2020). The general term ‘megaproject’ covers large, long-term and highly complex interdisciplinary projects (broad or narrow), normally characterized by a large investment commitment in development and implementation mostly by public funds, (infrastructure projects in cities, logistics such as high speed trains, aircrafts and airports, space technologies and renewable energy systems etc.) and great collaborative complexity (especially on an organizational level), with a long-lasting impact on the economy, the environment and society (Priemus, Flyvbjerg, & van Wee, 2008; Hu, Chan, Le, & Jin, 2015). Many future megaprojects will respond to global crises such as that of the COVID-19 pandemic and the grand challenges related to climate change and the UN Sustainable Development Goals (SDGs), which can be challenging to integrate into education; thus a framing of societal megaprojects to feasible educational megaprojects is necessary.

2.2 Megaprojects in Engineering Education

To frame the concept of megaprojects to be applicable within engineering education, we argue that it is necessary to work with the concept of 'black boxes' in the megaproject, with systems, or parts of a system, only considered in terms of inputs and outputs. Black boxing thereby refers to the process through which users (in this case engineering students) can have a general understanding of the system and its function without necessarily knowing all of its specificities. An example could be working with electricity grids and how to store energy from wind turbines, while not necessarily knowing the details of the wind turbine itself. In engineering, this is a well-known phenomenon, and to be able to bring real world problems and grand challenges into engineering education, this is a necessary part of the megaproject design. Advantages of this approach includes students learning to analyse relations in a system and to situate their specific knowledge, design or product within the overall system as well as an overall understanding of its relation to other disciplines beneficial for future interdisciplinary collaboration.

Since megaprojects require more resources than are usually available within a course or semester project, as well as more time to mature scientifically, technically and socially, it will be necessary to operate not only with black boxes in a system, but also with 'black phases'. Here, we refer not to a black box in the technological system, but instead a black box in the process of engineering. Most likely, students are part of just one or a few project phases—e.g. problem identification, problem analysis or problem-solving—essentially subjecting other project phases to black boxing, through which students hand over the results of a specific project phase to another team to continue the work into the next semester.

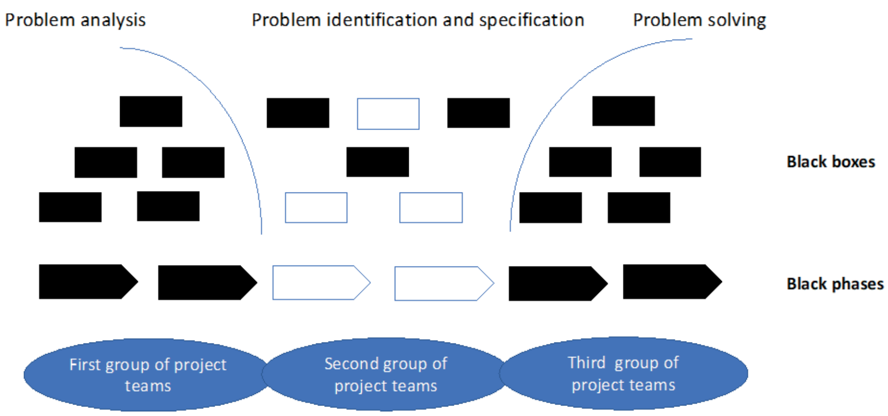

Figure 3: Black boxes and phases in projects

The phases can be defined and overlap in different ways; however, overall the process can be divided in two comprehensive phases: the *problem* phase, consisting of problem analysis and identification, with the aim of reaching a requirement specification; and the problem-*solving* phase, with the aim of develop a solution to the identified problem. Thus, when megaprojects run for several semesters, the first cohort of students works on the initiation, analyses and definition of the problem, while the second cohort works on requirements as part of the definition and design phase, and so on. The phases are equally important, and through experiencing different projects, students accumulate learning experiences related to all phases.

In a megaproject, a phase is not necessarily running for a single semester. Sometimes problem analyses or solving is done in iterations or for a longer periods of time, and for each phase several project groups join, These project groups might work on various tasks which will represent various credit points and thus with different workloads.

While a megaproject can be a feasible way to address complex problems such as those defined by the SDG's, there are many inter-related problems and a broad solutionspace. In this sense, the megaproject helps shed new light and new perspectives on challenges where we do not yet have a full understanding of the problem or limited current technical solutions to address it. While the students are expected to take a certain perspective in a megaproject and work only in one phase (e.g. problem analysis) in detail, it is considered a core competency to be able to understand and contribute to the alignment of different phases in the particular megaproject to help maintain an overview. This is particularly relevant when educational megaprojects relate to and collaborate with real-life megaprojects and external partners, either involving student projects over longer periods of time with several student teams and clusters involved, or where students work e.g. on one specific requirement in a sub-project but still need to understand its relation to other phases, as well as the overall aim of the project.

2.3 Interdisciplinarity in Megaprojects: A Spectrum

Whereas real-life megaprojects are most often considered broad in terms of interdisciplinarity, educational megaprojects can be modelled within a narrow inter-discipline scope, e.g. by dividing certain phases of the project across semesters. One such example is the AAU satellite project, which started up at the Department of Electronic Systems at Aalborg University. The project combine electronics and physics (space science) to build a fully functional satellite, and it has run through several phases, each corresponding to one semester (Larsen, Nielsen, & Zhou, 2013). In comparison to other narrow interdisciplinary megaprojects, this project is unique in adding a further 'product in operation' phase to the usual development of models and prototypes in PBL projects (Larsen et al., 2013; Zhou, Kolmos, & Nielsen, 2012). Another example is AAU Racing, where students, with a few exceptions, design all parts of a racing car. The product of each project is developed into a prototype and, in some projects, the engineering design is supplemented with a business plan and cost analysis (AAU Racing, 2020). There are many more variations and options, but characteristically, for the more narrow interdisciplinary megaprojects in engineering education, the focus is on a common product.

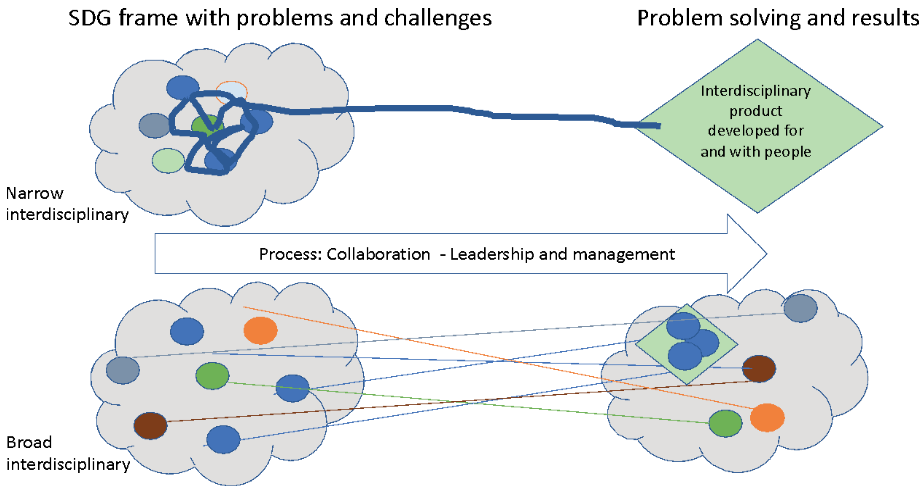

Figure 4: Types of narrow and broad megaprojects

The broad interdisciplinary megaproject that involves multiple disciplines, like the narrow, can span several semesters. For example, at AAU the megaproject 'Simplifying Sustainable Living' spans two years (AAU, 2020), with different focus areas highlighted (e.g. waste, green consumption and transportation). The first phases can involve identifying, analysing and even redefining a complex problem (for instance, the challenge 'Eat Locally' was renamed 'Eat Sustainably' as project groups found that locally produced food and sustainability did not necessarily correlate). Other phases can focus on specifying criteria for solutions, potentially defining additional narrow interdisciplinary megaproject proposals.

Compared to narrow interdisciplinarity, the broad interdisciplinary megaproject has a more complex organization, combining multiple disciplines that do not necessarily share the same knowledge paradigm, scientific methods or even scope. Thus, while an engineer and a social scientist may disagree on knowledge definitions and methodologies, it is much more critical if one understanding of the problem and aim of a sub-project within a megaproject conflicts with, or even counteracts, the aim of another. Therefore, even though the problem and solution phases and their products (black-boxed or otherwise) are equally important in broad interdisciplinary megaprojects, they must be modelled to , emphasise the precise contribution of different (and perhaps even conflicting) academic approaches and perspectives to improve and nuance the project's success criteria. The endpoint is a combination and interrelation of different systems, rather than one specific common product.

2.4 Complex Problem-Solving in Varying Project Types

Complex problem-solving competencies can ideally be achieved in all complex project processes, including discipline-oriented multi-projects as well as narrow and broad interdisciplinary projects (Attri 2018). The following Table 1 outlines the variation in some of the complex problem-solving competencies. Moving from left to right in the table, there is an increase in complexity in the contextual scope of the problem analysis, as well as the approach to design innovation.

	Disciplinary approach	Narrow interdisciplinarity	Broad interdisciplinarity
Project types	Discipline and multiprojects	Interdisciplinary projects Narrow megaprojects	Broad interdisciplinary megaprojects
Problem analysis	Understanding the problems in the discipline domain and how the discipline relates to other disciplines	Understanding problems related to parts of a system or parts of a process by combining a few core disciplines	Understanding problems in a comprehensive system perspective by making a synthesis of different discipline approaches
Problem-solving	Incremental product/service innovation (redesign what is)	Product/service innovation (design to substitute)	System innovation (design to change)
Project management	From stable teams and structures - to - agile systems/flexible structure with ad hoc groups		
Collaboration	From simple collaboration within same knowledge paradigm - to - difficult collaboration with different knowledge paradigms		

Table 1. Combining problem-solving competencies and project types

Table 1 stresses that increased complexity in problem-solving not only influences the content dimension, but also complexity in terms of collaboration and project management processes. The collaboration and organization of the project groups can vary greatly from having a simple and fixed structure of coordination to one that is fluid with emerging ad hoc groups and a focus on agile project management methods to involve more sub-teams in decision-making processes. However, as the complexity increases from a complex discipline specific project to narrow and even a broad interdisciplinary project, the need for agile systems and flexible structures increases due to the increased uncertainty related to both knowledge domains and potential solutions.

3 Final Remarks

In this paper, we have presented a project typology based on two dimensions: 1) the scientific content and problem scoping, ranging from simple and complicated problems to complex and interdisciplinary problems; and 2) the size and organization of the team(s) implicitly involved in project management processes on varying levels. Combining these two dimensions results in four ideal types of educational project categories: *single discipline projects, multi-projects, interdisciplinary projects* and *megaprojects*. We relate this to the distinction between narrow and broader interdisciplinarity and propose different variations including discipline specific multi-projects with several groups; the narrow one-group interdisciplinary project; the narrow interdisciplinary megaproject across groups (narrow by black-boxing parts of the system/processes); and the broader interdisciplinary megaproject across groups, including a comprehensive system perspective.

While the problem and solution phases of the project are obviously closely linked to the content, the learning potential is very much linked to the generic competencies obtained through interdisciplinary project work, both in terms of problem analysis, problem solving, collaboration and project management. The broader the disciplinary team constellation is in a multi- or megaproject, the more emphasis is put on students' complex problem-solving and collaboration competencies within and across groups. Furthermore, in comparison to narrow interdisciplinarity, a broad interdisciplinary approach will challenge the students to understand and communicate the qualities and contributions of their own discipline, as well as its boundaries and interaction with other disciplines.

In this paper, we have presented an overall conceptual framework for project types and complex problem solving competences. Future work includes studies to elaborate on the dimensions of the different project types, and explore how the framework can be appropriated to different problem solving competences e.g. entrepreneurial competence, business competence or digital competence.

Educational megaprojects combine the challenges of complex technological systems and complex collaboration patterns, and this type of project can be seen as bringing together competencies from other types of projects and adding both a societal and an intercultural dimension to the learning experience. Compared to the great challenges of our time, living in what has been coined a 'global village', where citizens struggle to obtain sustainability, the broad interdisciplinary megaproject holds a consolatory prospect for future engineering education.

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Educating Engineering Educators for Sustainability – a case of online resources for staff development

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Abstract

Engineering Education for Sustainable Development (EESD) has been on the agenda for decades in order for engineers to develop sustainable technology for future societies. Increased international attention to the signs of an overarching sustainability crisis have further increased the sense of urgency in order to move from sustainable discourse to actions – in industry as well as in educational systems. At Aalborg University, several actions have been taken in order to highlight the importance of sustainability in engineering and science education. As an example, in the beginning of the 1990s, all engineering students entering the University were placed in inter-disciplinary groups and faced with sustainability as a crosscutting semester theme. Likewise sustainability in different shades has been introduced as semester themes within programmes initiating engineering and science students to identify, analyse, formulate and address sustainability challenges in science and engineering. Furthermore, sustainability issues have been introduced in workshops for students and staff, and sustainability has been an integrated perspective in the developments of new prototypes and products in problem based projects. The challenges have however been to balance the focus on sustainability with more domain specific perspectives – to foster engineers with enough engagement and knowledge to contribute to a sustainable development in their everyday practice, and knowing when to bring in sustainability specialist when needed. The comprehensiveness of the United Nations Sustainability Development Goals have recently underlined the need for combining the generic with the specific in meaningful ways in order to cope with the complexity of the sustainability challenge. In this practice paper, we present an initiative to support staff in engineering and science to integrate sustainability in their educational practice. The online resources are organised in three stages of ambition supporting staff in: i) making students aware of the sustainability challenges in relation to their study domain, ii) providing students with an entrance to know more about sustainability, and finally yet importantly iii) empower students to do more and take action in their project to contribute to a more sustainable development. As such, the on-line resources are presented as a way to frame education for sustainability for engineering and science students, as a stepping-stone for staff to appropriate EESD for specific programmes.

Keywords: Sustainability Education, Engineering Education, Online resources, Staff training.

Type of contribution: Practice paper

1 Introduction

The discourse arguing for universities to play an active role in creating a more sustainable world is not new. In the last decades, guidelines and procedures have been developed at the conceptual level, prescribing how to integrate sustainability in universities - including education, research and management (Wright, 2005). Additionally, publications on education for sustainable development (ESD) have been increasing in the last three decades. Such increase is partly due to research and practitioners' publications on ESD, covering its learning principles, integration, pedagogy, students' perspectives, capacity building, and campus management. Likewise the social and political sense of urgency to address sustainability problems has increased, as for instanced exemplified by the United Nations Sustainable Development Goals (United Nations, 2015) and the Paris Climate Accords (United Nations, 2018).. As a consequence, more universities reflect what it takes for a university to integrate ESD at a systemic level.

Staff training programmes are part of a comprehensive strategy to implement ESD in higher education. The integration of ESD and the institutional processes that can enable a systemic, transformative and deep-rooted integration of sustainability depends largely on its staff, their willingness and capabilities to support such processes. It is through staff training programmes that in-service teachers are able to gain an understanding of sustainability by acquiring knowledge and developing competences to re-design their courses for ESD . Such programmes present the possibility for institutions to 'use' their staff as starting points to bring change from a bottom level (Barth & Rieckmann, 2012).

In engineering education, staff training seems to be inadequate, ineffective and does not reflect the demands on engineering educators regarding ESD, including its conceptualisation, integration, learning outcomes and teaching and learning activities (Barth & Rieckmann, 2012; Roberts & Roberts, 2008). Furthermore, designing appropriate learning activities for staff training should follow an approach similar to the one taken in developing the students' curriculum. Additionally, according to Sharpe (2004, cited by Roberts & Roberts, 2008) staff training activities should:

- *Allow for knowledge construction both individually and in collaboration*;
- *Encourage knowledge to be applied effectively within professional roles allowing the '**knowing that**' to be updated;*
- *Encourage learners to interrogate and engage with their developing knowledge in order to externalize and make explicit the **'knowing how'**, so that it can be shared and learnt from, to the benefit of both the individual and the organization; and*
- *Incorporate the values and ethical practice of the profession to reaffirm **how knowledge is used in practice***

Staff training activities should not merely be a platform for knowledge construction and development of new communities of practices; it should also create opportunities for different, progressive, levels of engagement and learning in engineering education for sustainable development (EESD). Additionally, the staff training activities should be transferable, with immediate application in practice. This should include activities that can be applied in teaching practices and facilitate students' learning for sustainability.

This best-practice paper presents an initiative to support staff in engineering and science to integrate sustainability in their educational practice. The initiative concerns an open online course for staff and has been developed as and for a problem based learning approach. Problem-based learning (PBL) is one of most suitable learning approaches to educate for sustainability, as learning principles that characterise both PBL and ESD overlap, including learning principles such as problem orientation, exemplary learning, contextual learning, experiential learning, interdisciplinarity, and collaboration (Guerra, 2014). PBL is a process-oriented and student-centred approach, where students have ownership of the learning process and are primarily responsible for the decision making process (Guerra, 2017).

In the following sections, the overall conceptual design (section two) and the on-line material (section three) will be presented, followed by concluding remarks (section four).

2 Developing a framework to design an online course – becoming aware, knowing more, doing more

The overall aims of the course is to support staff in: i) helping students to become aware of the sustainability challenges in relation to their study domain, ii) providing students with an entry point to know more about sustainability, and finally, yet importantly iii) empower students to do more and take action in their projects, to contribute to a more sustainable development.

To fulfil the aforementioned aims, we propose a framework to design an online course organised in three levels of ambition: '*becoming aware*', '*knowing more*', and '*doing more*' (see figure 1).

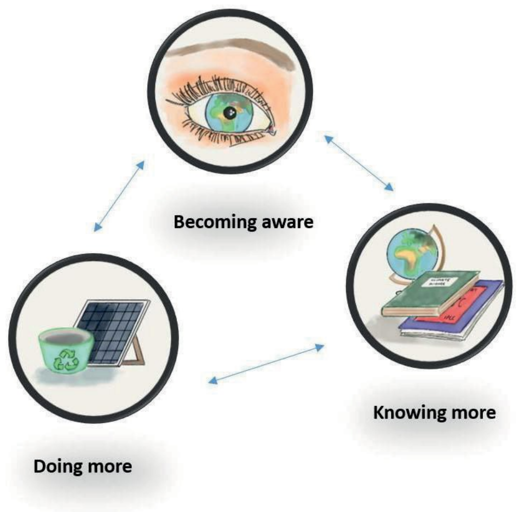

Figure 1: The interplay of the three dimensions in the on-line resources: getting aware, knowing more and doing more.

The framework and the three levels of ambition emerge from our experiences and reflections as lecturers and supervisors at Aalborg University, a PBL environment at the system level. For several years, we have been developing and delivering courses, workshops, seminars and supervising students' projects with, and for sustainability. The overall goal has been to educate AAU engineering students for sustainability. However, the different learning activities have been addressing different learning objectives and levels of development for ESD. For example, in the B.Sc. on Media technology, 1st and 2nd semesters, sustainability has been integrated into the project's sub-theme. In other programmes, seminars and workshops took place to create awareness and basic knowledge about how sustainability topics can be related to disciplinary fields. Nevertheless, we soon recognised that the learning activities for sustainability as well as the learning objectives needed to be organised and reflect progression in educating for sustainability.

We consider that the three levels of ambitions that compose the framework created to design the online course address the aforementioned needs that emerge from our practice and reflections. '***Becoming aware***' aims to create awareness of the role that engineers have in addressing the sustainability challenge. As a first step, there is a need to recognise why engineers, in general and within the expertise of study, can contribute to a sustainable society. After such a recognition, there is a needed to expand and qualify student knowledge about sustainability. This is the target of '***knowing more***', where sustainability, its complexity and principles, needs to be conceptualised and understood before it can be integrated into practice. In this dimension, it is not expected that students will develop expertise in sustainability sciences, but rather a '*know what*': understanding how sustainability is defined within existing frameworks and knowledge domains. Having established a knowledge base, students can start to re-construct and refine their knowledge about sustainability to address real life sustainability problems, i.e. '*know-how'* and the knowledge thereby internalised might even become a platform for identity development, i.e. '*know how to* *become'*. With this ambition, '***doing more***' implies that students engage in formulating and solving sustainability problems in a competent way. They become agents for sustainability.

Even though the framework to design the online course emerge from authors' practice and reflections, they relate with existent theoretical and empirical literature on ESD.

For example, a recently study published by Servant-Miklos et al (2020) "*presents different patterns of change for students' development of sustainability awareness and interest during the process of acclimatisation within their engineering studies*", highlighting the interplay between affective, cognitive and action-oriented dimensions of learning. Using a qualitative longitudinal study involving 16 students from four different engineering programmes, four categories emerged from the study: (1) no interest/ little awareness, (2) little interest/ basic awareness, (3) basic interest/ basic awareness + advanced domain specific awareness, and (4) active interest/ advanced (systemic) awareness. In this context, awareness is defined as "k*nowledge and understanding of the sustainability crises",* and interest as*" the propensity to seek out information about the sustainability crises*".

Furthermore, Sterling (2005) refers to three levels of learning towards sustainability, which are seen as consecutive and progressive. They are:

- Basic learning, implying "doing things better" i.e. trying optimise technological sub-systems from within a disciplinary knowledge domain. One can say technology is perceived as the solution and remains within "disciplinary silos". This can be related to becoming aware of the sustainability impacts from specific types of technology.
- Meta-learning, implies "doing better things", i.e. requires stepping out and recognising the relations between different knowledge domains within a wider social-technological perspective. Students then have to become aware of how different stakeholder interests play a role in the way technology is developed, understood and used.
- Epistemic learning, can be interpreted as "doing things differently". Sterling relates epistemic learning to a "helicopter view", i.e. seeing things differently by reconstructing knowledge domains, establishing new community of practices, and recognising the existence of alternative paradigms. It is about re-thinking societies in what Mills (1959) termed sociological imagination, where students need to create a "*vivid awareness of the relationship between experience and wider society*" (Mills, 1959).

These three levels underline the action-oriented approach (different levels of 'doing') of our course framework, but it also underlines the progression in knowledge from disciplinary to interdisciplinary knowledge; from silo thinking to embedded contextual awareness. This is emphazised in the on-line resources by helping staff to facilitate students in rethinking their discipline from a sustainability perspective. We do this first of all by making them aware of the inter-connectively between their discipline and sustainability. Secondly, by using a case approach as a platform to further study and get to know more about existing interrelations. Finally, we use a project oriented approach to get students actively doing more in order to propose new interrelations and thereby new potentials for sustainable developments. 'Knowing more' without 'doing more' would lead to a weak response to the sustainability crisis, but at the same time the consecutive nature of Sterling's three levels of learning underlines that actions for sustainability should build on a solid knowledge base.

The problem-oriented and project-organised learning approach includes the 'know why', which is needed in order to actually consider and validate that the paths taken are actually for the better or is actually making a difference. The 'know why' is deeply related to the problem design approach in PBL (see Holgaard et al., 2017). The problem identification and analysis which is a part of the problem design process requires the learner to reflect on both the personal and the context-dependent motivations to address the problem. In that way, the learner doesn't just construct or reconstruct their own knowledge – it is a triple loop learning process, where 'triple loop learning is learning that opens inquiry into underlying *whys*' (Isaacs, 1993).

3 Presentation of the online material

The online course on PBL and Sustainability we present in the following section is for staff who want to integrate sustainability in engineering programmes or courses and want to learn more about how PBL and sustainability can be interrelated in curriculum design and practice. The course is both for teachers in engineering programmes and curriculum designers in a PBL environment who want to integrate sustainability in the curriculum. The course is however not to be mistaken for a course introducing staff to sustainability science (or to problem based learning, for that matter). It is strongly recommended that such courses supplement this course. In this course, the aim is therefore to help staff to combine PBL and sustainability, rather than to teach about the domains as such. The team behind the course included engineers, sustainability scientists, education philosophers, as well as PBL researchers in order to address this crosscutting challenge.

The online material for staff on PBL and sustainability introduces different types of resources, including:

- Video materials to share ideas and experiences with education for sustainability.
- Recommended literature and links to share materials that have been beneficial for teachers as well as students for self-study
- Examples of best practices - to inspire educational designs and the facilitation of activities in a problem-based learning approach.
- Facilitating questions in order to initiate further reflections on PBL and sustainability.

In the next section, we elaborate on the online resources prepared for each of the three phases: becoming aware, knowing more and doing more.

Becoming aware

The first process in educating engineering students for sustainability is to facilitate student awareness with regards to the role of their future profession in addressing sustainability challenges. Although sustainability is a discipline in itself, it is also an embedded part of engineering. At least in the professional sphere, students to some extent see faculty as a role models. Therefore, it is crucial that faculty can argue *why* an engineer, in general and within a specific domain, has an important role to play in creating more sustainable societies. To support faculty in their argumentation, the online resources include a video providing an example of such an argument for engineers for sustainability – in general and exemplified in relation to specific domains. Furthermore, faculty can find links to recommended literature on Education for Sustainable Development (ESD).

In a problem-based learning environment the ambition is however not only for faculty to present arguments and express their own awareness about the interrelation between sustainability and particular disciplines – it is just as much a matter of getting students to construct their own argumentations and become aware of their personal role as engineering students and future engineering professional. In the online resources, discussions about the role of sustainability are facilitated by providing a structure and an example of how to facilitate this inquiry process (see example box 1). The idea of the inquiry process is first of all to create reflection on the interlinkages of sustainability and engineering, which creates the baseline for students themselves to point to potential knowledge gaps

To maintain the momentum of interlinking sustainability and disciplinary perspectives, questions for further reflection are provided, with core questions like:

1. What would you like to learn more about in studying the relation between your field of study and sustainability?
2. Do you think you will solve sustainability problems in the future with the help of your profession – and if so, how will you make sure that new solutions are more sustainable than the previous?
3. What obstacles do you see when working with sustainability in relation to your specific field of study?

BOX 1:

The workshop “Nanotechnology and Sustainability” was held for first year’s students at the Bachelor programme Nanotechnology at Aalborg University. Approximately 25 students attained the workshop, which is part of the course “Problem-based learning in Science, Technology and Society”.

The workshop consisted of two parts. In the first introductory part, students were asked to reflect on why they chose to study nanotechnology and what they expect to work with when they finish their education. In the second and main part of the workshop, focus was on sustainability: how do the students define sustainability and to what extent do they think sustainability is relevant for a nanotechnologist.

In order to structure the discussion on why students had chosen to study nanotechnology, Socrative (socrative.com) was used. Socrative is an online tool to get instant feedback from students on questions asked. With permission from the students, the answers where shown in class, which gave the possibility to elaborate upon the answers given. Some of the answers could also be used in the second part of the workshop, when it was discussed whether or not a nanotechnologist should work with sustainability.

In the workshop, the students had not been introduced to the concept of sustainability. Their input was therefore based on their prior knowledge and understanding of the concept. The students were asked to form small groups with 3 students in each group. Each group had to write their definition(s) of sustainability on a poster. Afterwards, the groups had to present their definition of sustainability in plenary. For most groups, environmental sustainability was most dominant in their sustainability mindset, which was also reflected in the examples they gave: they could work on optimising the utilisation of solar panels, help improving water purification technologies and so on. It was difficult for them to relate to economic and social sustainability.

Knowing more

What Sterling (2005) calls education *about* sustainability implies that students expand their knowledge base in terms of sustainability. The strategy has in many situations been to integrate courses on sustainability in engineering programmes to introduce students to sustainability science. Such courses however, need to consider that the target group is not comprised of sustainability specialists. So, before moving into conceptual frameworks from sustainability science on how to *deal with* the sustainability challenge in specific situations – it is recommended to foster an overall understand of the complexity of the sustainability challenges as such. In the online resources we provide a specific example of a video introduction to the grand sustainability challenge, which was recorded in partnership with Erasmus University Rotterdam. The angle taken in this video sits at the intersection of ecology and political economy, bearing in mind a target audience of non-specialists. The video targets the sweet spot of the *sociological imagination*, at the point where the personal (e.g. recycling your own trash) becomes the social (i.e. the global plastic crisis). It is also possible to use videos for students' preparation. Furthermore, students can be encouraged to read and look up literature and film productions on the overall sustainability challenge based on examples provided in the online resources; books such as Klein's *This Changes Everything* (2014), or Wallace-Wells' *The Uninhabitable Earth* (2017), and films such as Al Gore's *An Inconvenient Truth,* Di Caprio's *Before the Flood*, and *A Plastic Ocean*.

When the students have obtained knowledge about the overall challenges of sustainability, they have the overview to contextualise sustainability to their particular domain of study. In the problem-based learning environment at Aalborg University, teachers have experienced that the use of cases is effective to motivate students to learn more about sustainability and study how sustainability relates to their particular discipline of study. The cases are designed to stress the relevance of sustainability for the specific programme. The approach has been to facilitate case-work on sustainability in specific disciplines, and in example box 2 there is a concrete example of how students were facilitated to interlink nanotechnology and sustainability, together with reflections from the facilitator.

Another way of using cases is to mirror real life engineering practice and challenge students to face the same dilemmas and challenges as in a real life sustainability project. We provide an online case mirroring a sustainability project, the so-called *Shanzu case* (UCPBL, 2020). The Shanzu case follows a project where the challenge is to improve the water and energy supply system for a school for disabled women in Shanzu, Kenya. The students are faced with the same challenges as in real life at different stages of the project. It can be used as a source of inspiration to create cases simulating the challenges of managing a sustainability projects in progress.

BOX 2:

After the students nanotechnology had had the possibility to define the concept of sustainability themselves (see box 1), the workshop changed focus. The teacher took over and presented, based on literature, different ways to define sustainability. The students were introduced to the three pillars of sustainability: the social, environmental and economic pillar. Throughout discussions subsequently, the students realised that their examples also had an economic and social impact. These were discussed in plenary.

After these discussions on defining the concept of sustainability, it had become time for the students to apply their newly acquired theoretical knowledge on concrete societal problems. On the basis of five concrete societal problems (water pollution, air pollution, energy efficiency, transport and health) students worked in groups of five students each to explore how nanotechnology can contribute to sustainable development within these fields. Relevant literature with regard to these societal problems was made available online beforehand. Students had though the opportunity to collect more literature. Each group was allocated one of the societal problems. They had to discuss two questions: 1) what are the causes and consequences of the problem and 2) how can nanotechnology contribute to solve the problem. The students had to make a short PowerPoint presentation to present their results. During the group work, the teacher had discussions with the groups and asked them various reflective questions. After the presentation the other groups had the opportunity to come with their comments and reflections to the other groups. In the last part of the workshop, the teacher presented causes and consequences of the societal problems and showed some YouTube movies that explained for example how to purify water by using nanotechnology. After these presentations it was discussed whether or not the solutions presented in the YouTube movies were sustainable or not.

Doing more

When students can move from the specific to the general, to capture and interrelate the complexity and the specifics, the students have created a knowledge-base to address real life sustainability problems. It then becomes more than just a matter of knowing more, as the students will in fact be ready to *do more* to foster sustainable development in a competent way.

A problem-based learning environment using real life problems creates a framework to push education from education *about* sustainability to education *for* sustainability. In this latter perspective, students actually make technological inventions, products, systems and environments for a more sustainable development. Projects are furthermore an opportunity to challenge disciplinary boundaries and this can be organised into more interdisciplinary projects such as for example mega-projects, where several student groups from different disciplines work on a real life wicked problem. (Holgaard et al, 2019).

BOX 3:

Students in the Bachelor programme Nanotechnology at Aalborg University are not obliged to apply the knowledge on sustainability acquired in the workshop in their project work. However, some groups have been triggered by the discussions they had on sustainability in the workshop, so they also integrated sustainability issues in the problem analysis of their project.

For example a group that wrote a project about the fabrication of aligned zinc oxide nanofibers via electrospinning. The introduce their project as follows: "*Environmental sustainability is an increasingly prominent issue, as global warming is approaching an irreversible state and energy sources like oil and natural gas are being depleted quickly. Thus, it is of interest to combat the threat of climate change and find a new form of energy production that can replace fossil fuels (…). Solar energy is of great interest as a renewable energy source (…). One promising type of solar cell is the thin film solar cell. Multiple thin film layers are deposited on a substrate to form an electrode. Nanotechnology is of great interest in this field, because when materials approach the nanoscale, the properties of said material change*." (Westerkam, Kristensen, Christiansen & Jensen, 2018: page 1-2).

On this project, the group had two supervisors: a main supervisor who is responsible for nanotechnology in the project and a co-supervisor who is responsible for putting the project's problem in a societal context, in this case a sustainable context. The co-supervisor was also the teacher of the sustainability workshop. It has been a huge advantage, that there was good cooperation between both supervisors. During supervision meetings with the group, in which both supervisors participated, the expertise of both supervisors was used to help students to integrate sustainability into their project. An additional advantage of this approach was that both supervisors got a better idea of the other's research competences.

However, to make such sustainable innovations, a careful identification and analysis of the problem to be addressed is needed in order to provide targeted solutions, and a comprehensive assessment of new solutions is needed in order not to create new (and maybe even more severe) sustainability problems. In other words, the process of identifying, analysing, formulating, solving a problem and then assessing the provided solutions in a comprehensive way creates the setting for integrating sustainability in engineering programmes.

When a PBL and Sustainability project unfolds, sustainability knowledge, skills and competences blend in with disciplinary competences to solve a real life problem – a problem that matters. In box 3 there is an example of how students from Nano-technology at Aalborg University integrated sustainability in their project work. In the on-line material, this and other examples are included for inspiration.

4 Final remarks

In this practice paper, we present an initiative to support staff in engineering and science to integrate sustainability in their educational practice.

The examples from Aalborg University show that the effort to foster education for sustainable development can re-enforce student engagement for sustainability. The intention is that such an engagement will follow students in future projects as an embedded way of thinking engineering. The strategy leads to an interdisciplinary problem-based and project-organised approach supported by active as well as reflective learning activities in courses.

It is important to note that this strategy is not limited to a one-project approach which could lead to students developing a tunnel vision and a reductionist sustainability approach. In other words, becoming aware and knowing more is not a one-time process – it is a continuous process of getting a conceptual understanding of the complexity of the sustainability discourse. The UN sustainability goals for one thing underlines this complexity. Another condition is that students are able to transfer their experiences to other situations, and providing students with a conceptual understanding of sustainability is needed just as well. It is the combination of theory and practice which qualifies the problem solving process, and quality solutions are crucial tackling the urgency of the sustainability challenge.

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INGENIA, a novel program Impacting Sustainable Development Goals locally through students' actions

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Abstract

Spain's public universities agreed recently to contribute to the 2030 Agenda of Sustainable Development Goals. The University of La Laguna (ULL) endorsed this agreement and launched INGENIA, which is a competitive funding program for projects conceptualised and performed by high school and undergraduate students, utilising a Project-oriented Problem Based Learning (PoPBL) strategy. This program addresses needs of the society in the Canary Islands; it supports participating students' development of knowledge and skills regarding: (1) relevance of the problem each student team identifies, and the (2) viability, (3) impact, and (4) endurance of each team's proposed solution.

Forty-seven students were anticipated to participate in the program; these students would be supported by 13 academic staff alongside 11 postgraduate students who would participate in a student-facilitators sub-program. INGENIA formally launched at ULL on 31 January 2020, but was interrupted in mid-March when Coronavirus resulted in the closure of all Spanish universities. To date, academic staff have served as mentors, advising student teams in choosing significant local SDG-related problems and writing proposals to address the four aspects listed above. Student-facilitators would support these mentors to help keep undergraduate students on track and motivated during their project work. INGENIA accomplished almost two of three stages and started its third stage which has been restructured to be performed online after COVID-19 lockdown: (1) informative and training actions for getting academic staff and students interested in participating; (2) training of the student-facilitators; and (3) project development and presentation. In the first two months, students worked on project proposal. In the subsequent three months the selected teams were to develop and conduct their proposals, then report and present results. The final presentations would allow students to pitch solutions to local companies and public institutions to help secure additional funding after the end of the grant-funded INGENIA period.

This paper provides details of the program, identifies methodological and pedagogical fundamentals upon which it is grounded, reports results of completed phases, and identifies implications that may be of relevance to other programs and in future iterations of INGENIA. The report may be of use to others wishing to conduct PoPBL and/or hands-on sustainability projects.

Keywords: Sustainable development goals, project-oriented problem based learning, service learning, students as facilitators, social student-projects.

Type of contribution: PBL best practice

1 Introduction

The public universities of Spain recently agreed to contribute to the Action Plan for the Implementation of their country's 2030 Agenda (Crue Universidades Españolas, 2018). This contribution involves generating and transferring knowledge and skills linked to Sustainable Development Goals (SDGs) and including sustainable values transversally in all actions. As part of this agreement, Spanish universities agreed to improve their learning, teaching, and students' participation processes to increase motivation for understanding and addressing SDGs through an active and collective mobilisation. To contribute to the Action Plan of the Spanish universities, the University of La Laguna (ULL) included in its 2019 governmental plan the support of the SDGs. In particular, ULL wanted to support initiatives that enhance social, economic, and environmental sustainability within the geographical context of the Canary Islands.

Aligning with the commitment of ULL, public universities, Spain, and United Nations, the authors developed the INGENIA program to attract and prepare students to face SDG challenges through active learning in the Canaries. INGENIA is focused on the needs of local society; it is fostering knowledge and skills development among students who participate and building understanding of sustainability among members of the community with whom they interact. The program uses Project-oriented Problem Based Learning (PoPBL) learning strategies to motivate students to find and propose solutions to real problems linked to the SDGs within their own environment. PoPBL is a coherent learning strategy to promote students' involvement in sustainability by helping them develop innovative solutions and take collective action (Haan, 2010; Rieckmann, 2012; Wiek et al., 2011; UNESCO, 2017). The program has a transversal and open nature, given that it is not linked to a specific degree, course, or problem. Moreover, it involves students and academic staff at university and high school levels. INGENIA invigorates transdisciplinarity by encouraging, motivating, and supporting students to find and analyse problems from various perspectives and work across disciplines.

Working within a traditional and slow-changing academic context, this program was not designed as part of the existing curriculum, but as an extra-curricular activity for changing students' awareness of SDGs and their surrounds, which has been recommended as a first step toward achieving more comprehensive curricular change (Lamborn, 2009). Program designers started by identifying best practices to educate students to create positive impact on their local society. To ensure impact, INGENIA was developed as a competitive funding program for students. Formal objectives of INGENIA are to:

- Train university and high school academic staff in using active learning strategies to support SDGs.
- Educate postgraduate students, and academic staff, in facilitation techniques and strategies to guide students in developing complex projects linked to SDGs.
- Implement, in real-life settings in the Canary Islands, student projects that have high potential for positive impact.

These objectives are to be accomplished in three stages: (1) Informative and training actions, (2) training of facilitators, and (3) project development. These stages are explained in more detail in section 4. Unfortunately, the emergence of COVID-19 forced INGENIA to pause at the beginning of the project development stage and the national lockdown delayed the third stage as of this writing. During the shutdown, the authors are pushing the project ahead by further analysing student-facilitator data collected in an earlier pilot study (preliminary analyses of these data supported the design of INGENIA) and studying relevant literature and creating web-based education resources aligned with the topics of INGENIA. In April 2020 the program was restructured and adapted to work online. The following text provides detail regarding the INGENIA program with the aim of sharing initial learning “takeaways” realized by the authors based on work completed before the COVID-related university closure.

2 Description of the context

INGENIA is a program developed and executed by three entities working in collaboration: the ULL Vice-chancellor of Students Office, the General Foundation of the ULL (FGULL), and the Cabildo of Tenerife (Canary Islands) which solicited and funded the university’s participation. INGENIA is open to the participationby:

- ULL undergraduates and upper high school and vocational school students from academic institutions located in Tenerife. These students form the core of the program collaborating in teams of 2-5 members to send proposals to the program. INGENIA was open to all ULL’s undergraduate programs and any pre-university A level high or vocational school from Tenerife. Students could participate in one of the following tracks: undergraduate students’ track (ULL) or high/vocational school track (HS/VS). It was not possible to create mixed ULL-HS/VS teams, but undergraduate ULL students had the possibility of creating teams with students enrolled in different programs (see table 1).
- ULL academic staff and high school and vocational schoolteachers participating as mentors of student teams during preparation of proposals. These educators serve as student teams’ mentors and guarantors for the execution of the various projects.
- ULL postgraduate students serve as learning facilitators. These students must complete a training program before joining in order to most effectively support student teams.

Table 1: Student teams and their proposals sent in INGENIA.

Team	Track	No. of participating students and programs involved
P01	HS/VS	2 students from higher level vocational school program on education and environmental control.
P02	ULL	5 students from Accounting and Finance degree.
P03	ULL	5 students from Tourism degree.
P04	ULL	3 students from Education, Biology, and Environmental Sciences degrees.
P05	HS/VS	3 students from high school.
P06	HS/VS	2 students from high school.
P07	HS/VS	3 students from high school.
P08	HS/VS	2 students from high school.
P09	ULL	5 students from Tourism degree.
P10	ULL	2 students from Agricultural and Rural Environment Engineering degree.
P11	ULL	4 students from Tourism degree.
P12	ULL	2 students from Nursing degree.
P13	ULL	5 students from Accounting and Finance degree.
P14	ULL	4 students from Tourism degree.
P15	ULL	5 students from Environmental Sciences and Psychology degrees.
P16	HS/VS	5 students from high school.
P18	ULL	4 students from Accounting and Finance degree.
P19	ULL	2 students from Nursing degree.
P20	ULL	4 students from Accounting and Finance degree.
P21	ULL	5 students from Accounting and Finance degree.
P22	HS/VS	4 students from high school.
P23	HS/VS	4 students from high school.

INGENIA started with a public promotion campaign on 10th January 2020 and it was expected to finish with a "pitch event" to present students' solutions to the companies and administrative bodies in Tenerife on July 17th. The program was promoted by using social networks, e-mail, and presentations in ULL. FGULL also contacted all high and vocational schools of Tenerife. As a result, the program received 23 proposals at the stated deadline, 8 March 2020. The program also involved 23 mentors (one mentor linked to each proposal) and 24 postgraduates received specific training to become facilitators. According to the initial timeline of the program, an open call was planned that would offer 11 fellowships in March for individuals wanting to work as facilitators. However, the program was paused before the call opening due to the confinement measures linked to the COVID-19.

In April 2020 the program was restructured and adapted to work online through ULL's Google Education services and the dates for the selection of facilitators, student work, and final pitch events were postponed (see section 4). The call for facilitators was reopened in April right after the restructuring of the program.

3 Pedagogical framework

The INGENIA program is not linked to existing curriculum subjects. Consequently, it has not been constrained by regulations and legal requirements governing the curriculum. However, participating in INGENIA has been increasing the students' workload. As a result, INGENIA might not appeal to *all* students, but rather to students concerned about sustainability and social issues who wanted to volunteer. The program encouraged students to address SDGs by implementing active learning strategies like Project-oriented Problem Based Learning (PoPBL) that have been proposed as effective to achieve this purpose (Lamborn, 2009; Strobel & Van Barneveld, 2009). The PoPBL model is widely used in engineering education and its features are applicable to the main needs of the program: (a) it is a collaborative and cooperative learning, (b) it requires the identification of a relevant problem, and (c) it is focussed on developing a product, process or solution to create positive impact on the local society. In an a highly structured synthesis of meta-analyses on PBL learning outcomes, generated by others over a 15-year period, Strobel and Van Barneveld (2009) found that PBL was superior to traditional classrooms "when it comes to long-term retention, skills development and satisfaction of students and teachers, while traditional approaches were more effective for short-term retention as measured by standardized board exams" (p. 44).

In INGENIA, implementation of PoPBL was to be applied throughout the project development (third stage) of the program. Because INGENIA is a funding program for students, student teams were required to dedicate significant effort to designing and writing about their proposed concepts. It was expected that all participating students, who were self-selecting, would thus be intrinsically motivated. It was recognized that just having a good idea would not guarantee success, and this is why mentors were assigned to help students teams at the beginning of the process. The staff mentor has been the expert who guides the students in finding the right problem, focussing on their solution, writing up and submitting the proposal idea with consideration given to the *relevance of the problem* as well as the *viability*, *impact*, and *sustainability of the proposed solution*. These four criteria are part of the evaluation process of the proposals and are explained in more detail in section 5. Mentoring was to be complemented by facilitation, and some of this was achieved prior to the COVID lockdown. It was recognized that during implementation of the successful proposals, students would need guidance and motivation to keep on track and not give up when encountering obstacles and challenges. Mentors selected for the INGENIA scenario were experts, but they did not necessarily have all the skills or time needed to fully support the students' projects. This is why INGENIA included a facilitator sub-program, for postgraduate (PG) students who could act as guides, and help overcome challenges. PG facilitators were expected to support students while planning their projects, by helping them limit procrastination, stay motivated and focused, and limit and resolve conflicts.

4 Implementation of the program

The INGENIA program was designed in three stages for (a) informing and attracting the potential participants (successfully completed), (b) training and preparing facilitators to support students (successfully completed), and (c) finding relevant problems, proposing achievable solutions and developing projects to implement those solutions (in-progress). The program was expected to run during the second semester from January to July 2020. However, the INGENIA program was altered after the COVID-19 lockdown to give additional time for the development of students' projects, until October 2020. Figure 1 shows the activities and the interactions between the three participating collectives (students, mentors and facilitators).

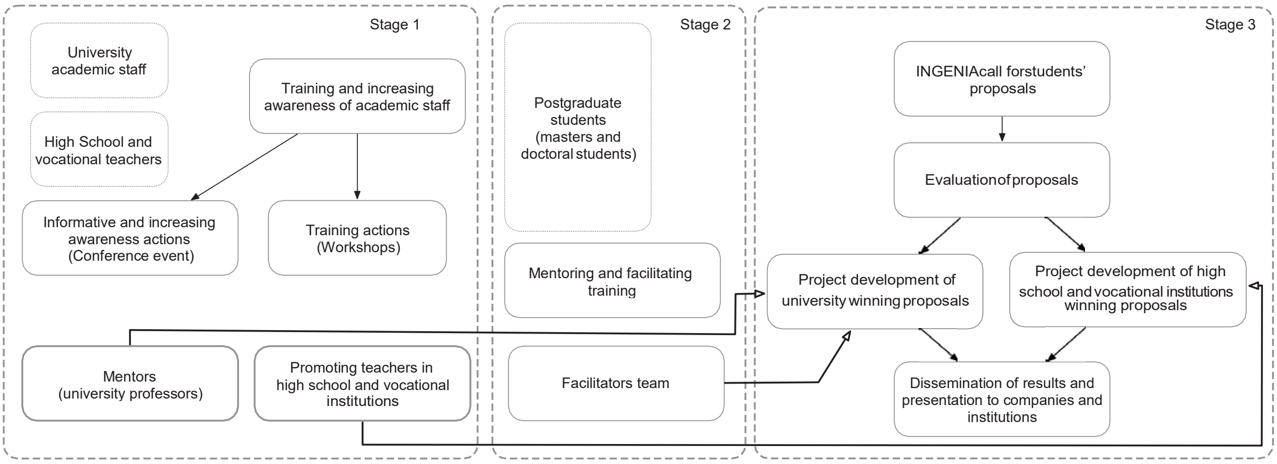

Figure 1: The three stages explaining the implementation of INGENIA

The three stages of INGENIA were designed as follows:

1) **Informative and general training actions**. Informative actions included a conference held at ULL on January 31st, the Changemaker Day, that showed how students can change the world. A total of 250 attendees, including ULL students, high school students, academic staff, and teachers, participated in this event. General training actions included: one workshop for academic staff and high school teachers interested in becoming mentors (with 12 assistants); and four workshops for undergraduate and high school and vocational students interested in participating in the program (1. *SDGs and university*, 2. *Collaborative creativity for sustainable development*, 3. *Lean methodology*, and 4. *Funding and investing to create social impact*) with a total of 100 attending students. These students participated also in networking actions with local companies and associations linked to social and environmental innovations. One goal of this phase was getting academic staff and teachers motivated to help students in writing their proposals. Each of these teachers was serving as mentors and guarantors for a team of students. Mentors were to assume financial responsibility for the project each of them backed. The primary goal, however, was getting students motivated to participate in the program and helping them to build new perspectives of the SDGs and building networks for finding relevant problems and proposing realistic solutions.
2) **Training of facilitators.** In a first phase, a group of 24 postgraduate students received specific training in participative methods to agree upon strategies and SDGs and facilitation processes and techniques. In a second phase, a fellowship call was open to all students who participated in the first training phase. Nine students passed the selection process (which consisted in the evaluation of merits and a personal interview by a selection committee) to get a fellowship to work as facilitators. The second phase also included specific training on PoPBL and academic motivation before the start of the fellowships. The goal of this phase was having a group of facilitators ready to work with students during the implementation of the students' winning proposals. Thus, facilitators did not participate in the process of helping the students chose the problem and write the proposals, but they will start to work with student teams during the implementation of their projects if their proposal is subsequently funded.

3) **Project development.** The last stage started with the call for students' proposals. The call was open from February 7th to March 8th 2020. A total of 23 proposals were received (15 from undergraduate students, 7 from upper high school students, and 1 from vocational students). Within three pages, each proposal had to justify the relevance of the problem as well as the feasibility, impact, and sustainability of the team's proposed solution. Other aspects required in the students' proposals were proper formatting, interdisciplinary, and equality. An evaluating committee composed of university experts evaluated all aspects of the proposals, assigning a 0% to 100% score based on the criteria showed in section 5. The threshold to have the possibility of getting a proposal

funded was 60% and 13 proposals scored above this. Primary goals of this phase were: developing students' proposal writing skills in the context of SDGs, choosing the best proposals, and supporting the students to maximise the probability of creating positive impact on the surroundingcommunity.

Table 2: Training and responsibilities of mentors and facilitators.

	Training	Responsibilities
Mentors	• Evaluation of relevance, viability, impact, and sustainability (Feb. 2020). • Transforming leadership (April 2020). • Project planning and managing (April 2020). • Technical meeting about INGENIA funding management and PBL process (April 2020).	• Helping student teams in choosing the right problem based on their common interests, background and INGENIA's program criteria: relevance, viability, impact, and sustainability. • Advising students in writing their proposal. • Managing project's funding. • Providing scientific and technological support.
Facilitators	• Participative methods, facilitation, and SDGs I (Feb. 2020). • Participative methods, facilitation, and SDGs II (May 2020). • Technical meeting about PBL process, team management and facilitators' roles. • Social communication linked to SDGs.	• Keeping students motivated and on track. • Solving conflicts between students. • Having weekly meetings with student teams and mentors to support the process and comply with objectives and deadlines. • Providing planning and managing support in coordination with the mentor. • Collaborating with INGENIA's managing team in getting info from student teams and mentors. • Performing research and disseminating tasks in coordination to INGENIA's managing team.

It was expected that winning teams would receive up to €1500 depending upon the amount required in the proposal and the criteria of the evaluating committee (the total budget available for students' proposals was €20,000). Students' projects were to be executed between March 23rd to May 22nd, but the pandemic caused by the COVID-19 affected this stage. At the time of this writing, the ULL Students' Vice-chancellor office and the FGULL have implemented adjustment measures to continue the project development stage by integrating online activity and work from home. At the end of the project-execution period, each team is to write a report to identify the impact of their solutions. Originally, it was expected that, after this report, students would participate in July 2020 in a public exhibition and in a pitch event to show their solutions to companies and public institutions with the aim of securing additional funding to continue their projects. However, the adjustment measures mean that student teams will be allowed to work on their field tasks during July, August, and September; this pushes the public exhibition and pitch events to October 2020. These events can be held online, if such is recommended by the health authorities.

5 Description of the proposals' evaluation process

There were two phases to evaluation of proposals by experts. Initial scoring was done by two experts who evaluated separately each proposal. The scores they proposed were then calibrated in a second phase, involving an online meeting. The weights and evaluation criteria (translated from Spanish, below) were use to score the proposals; this information was accessible to the participating students prior to submission of proposals:

C1. **Presentation and structure (5%)**. *Format, headings, and margins are adequate and follow the template. The text is clear and easy to understand and it is coherent with headings. References are included and used along the proposal. References have a coherent format (APA, Vancouver, etc.) Small details like isolated punctuation mistakes will not be penalised*.

C2. **Relevance of the problem (20%)**. *There is a theoretical framework or a valid precedent linked to the problem. The relevancy of the problem is explained by explaining its causes, previous experiences* *and/or previous interventions. The problem is clearly connected with one or more of the SDGs and this connection is clearly justified and documented*.

C3. **Viability of the solution (20%)**. *Objectives are clearly formulated (they are particular, evaluable, feasible, and are described in terms of improvement) and linked to the theoretical framework. The viability of the solution considers the local community in contact with the problem (e.g., the solution arises after a dialog with the affected persons or considers previous attempts to solve it by analysing its failures). The proposal considers the time available to perform the project, and has a realistic planning of tasks and resources*.

C4. **Impact of the solution (20%)**. *The future impact is assessed by using an efficiency index (e.g., number of beneficiary persons, recovered surface, estimated incomings, etc.). Efficiency indexes used in the proposal require a clear justification. It is not necessarily that the proposal presents a final solution, so prototypes will be accepted. However, proposals should include tests to ensure impact if the final solution is executed after the INGENA program ends. The solution must be well connected to the problem, and solves it credibly*.

C5. **Sustainability of the solution (20%)**. *The solution can be maintained over time. The financing required to maintain the solution over time is affordable. Additional funding resources are considered to support the solution after the INGENIA program ends. The solution does not require complex resources that may cause that the community to which the solution is offered could not make use of it.*

C6. **Interdisciplinary aspects (5%)**. *The proposal requires different disciplines. These disciplines are clearly integrated in the project.*

C7. **Integration of equality criteria (10%)**. *The proposal clearly considers the equality of opportunities, with independence of identity, gender, or the origin of any person. It is clearly specified how the solution affects equally to the improvement of opportunities to all persons*.

Proposals were assessed by experts in a double-blind assessment process. Each proposal was assigned to two experts who evaluated each criterion with an accuracy of one decimal place by using this scale: *Fail* (0.0), *Poor* (1.0), *Regular* (2.0), *Good* (3.0), *Very good* (4.0), and *Excellent* (5.0). The second phase of the evaluation was conducted via an online meeting of the same experts to reach consensus. At this stage, the score for each proposal was achieved by factoring in final score, using the following equation:

$$Score\ (\%) = \frac{(5 \cdot (C1 + C6) + 20(C2 + C3 + C4 + C5) + 10 \cdot C7)}{5.0}$$

Proposals with scores below the 60% threshold were rejected, and the evaluation committee elaborated a ranked the proposals over this threshold. In this phase, ranking was split in two separate tracks: *Undergraduate students' proposals* (ULL track) and *High school and vocational students' proposals* (HS/VS track). The budget allotted for track (a, university) was €17000 and budget for track (b, HS/VS) was €3000. Initially, it was not expected to receive a high number of proposals in the HS/VS track; however, the program allowed transferring budget between tracks if there were not enough successful proposals.

6 Results of the evaluation process

After the evaluation process, 13 proposals obtained a score over 60% threshold (8 from ULL, 4 from three different high schools, and 1 from one vocational school). The following table shows the ranking of the proposals after the evaluation process and the budget approved for each one.

Table 3: Ranking of proposals and allocated budget after the evaluation process.

Proposal	Track	C1	C2	C3	C4	C5	C6	C7	Score (%)	Budget
P11	ULL	2,0	2,0	1,5	1,0	2,3	1,0	0,5	31,0	0
P14	ULL	2,3	2,0	1,8	2,0	3,0	0,5	0,8	39,3	0
P07	HS/VS	2,5	3,5	1,3	1,8	1,5	1,0	2,0	39,5	0
P08	HS/VS	1,8	2,0	2,5	2,0	2,5	0,0	3,0	43,8	0
P09	ULL	3,0	3,3	2,3	3,0	1,3	0,5	1,3	45,0	0
P06	HS/VS	3,0	2,0	1,0	3,0	2,5	2,6	4,0	47,6	0
P13	ULL	3,3	3,8	2,0	2,0	1,8	1,0	3,0	48,3	0
P20	ULL	4,0	4,0	1,5	3,5	2,0	0,5	3,0	54,5	0
P18	ULL	1,5	3,5	2,3	3,3	2,8	0,0	3,5	55,5	0
P17	ULL	4,5	3,5	2,8	2,8	2,8	0,5	2,0	56,0	0
P05	HS/VS	2,0	3,0	2,8	4,0	2,0	2,0	4,5	60,2	1500
P02	ULL	2,8	3,8	3,3	3,0	2,8	2,3	2,3	60,5	500
P15	ULL	2,8	3,5	3,5	3,5	3,0	3,5	2,8	65,8	600
P03	ULL	3,8	4,5	3,0	4,0	3,3	1,8	1,8	68,0	600
P21	ULL	3,5	4,3	3,8	3,7	3,3	1,8	1,8	68,6	1000
P16	HS/VS	3,5	4,5	3,8	3,0	4,5	4,0	1,3	73,0	800
P22	HS/VS	3,3	4,0	4,5	4,0	4,3	1,8	1,7	75,4	1500
P23	HS/VS	3,3	4,0	4,5	4,3	4,0	1,8	1,8	75,5	1500
P10	ULL	4,8	4,0	4,0	4,3	3,0	4,0	3,5	76,8	1500
P01	HS/VS	3,3	4,3	4,5	4,0	4,3	2,8	2,3	78,5	1000
P12	ULL	4,8	4,5	4,5	4,0	3,8	4,3	2,8	81,5	1000
P04	ULL	5,0	5,0	4,3	4,5	3,0	4,0	4,0	84,0	1130
P19	ULL	5,0	5,0	5,0	5,0	2,0	3,0	5,0	86,0	1300

The total accumulated budget for ULL track was €7630; for HS/VS track it was €6300. As such, all proposals over threshold in both tracks were accepted. Vertical boxplots in fig. 2 show the distributions of HS/VS and ULL scores and the median value of the proposal scores for each track. The median score of rejected proposals was 43.8% (HS/VS) and 48.3% (ULL). The median score of accepted proposals was 75.4% (HS/VS) and 72.7% (ULL) (see Figure 2). P-value of Mann-Whitney Test between the two tracks for rejected proposals was 0.974, and for accepted proposals it was 0.998, so the median score did not vary significantly across tracks.

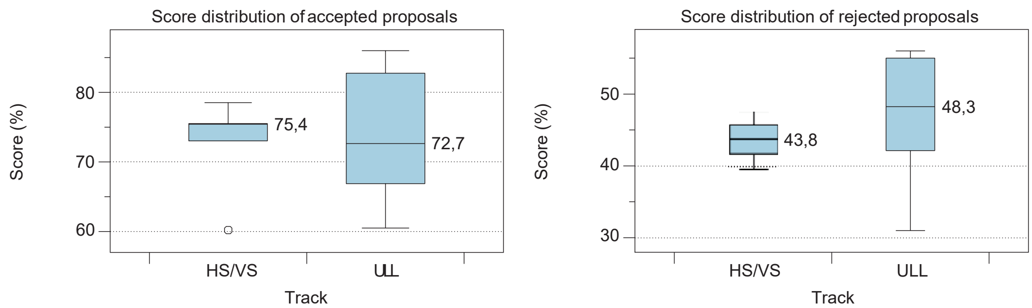

Figure 2: Score distribution of accepted proposals (left) and rejected proposals (right).

NOTE: Base of the box represents 1st quartile and the top of the box represent 3rd quartile. Whiskers represent variability under the 1st and over the 3rd quartile. Median values are indicated in each box and open dots represent outlier values. Shaded blue boxes represent 50% of data.

Regarding the allocated budget, the median of the proposals presented to the HS/VS track was €500 higher than those presented to the ULL track (see fig. 3, left). The budget claimed by proposals seemed to increase along with the quality and higher score given by the evaluating committee. However, the proposals with highest scores did not claim the maximum budget allowed (see Figure 3, right).

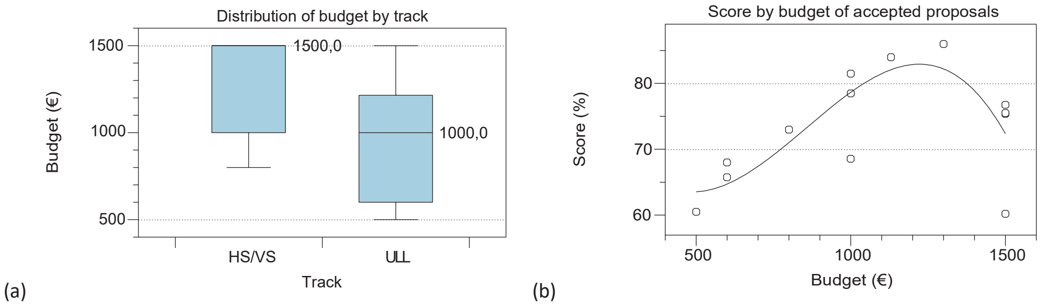

Figure 3: Budget distribution of the accepted proposals (a) and score by budget of proposals over threshold (b).

The results of the criteria evaluation of the accepted and the rejected proposals showed the weakest aspects of the documents sent to the program (see figs. 4 and 5). There were significant statistical differences between accepted and rejected proposals in criteria C2 (*Relevance of the probl*em), C3 (*Viability of the solution*), C4 (*Impact of the solution*), C5 (*Sustainability of the solution*), and C6 (*Interdisciplinary aspects*) (see table 4). These results reflect the evaluation process: it was expected that scores below threshold had significant differences in most criteria from those over threshold.

However, C1 (*Presentation and structure*) and C7 (*Integration of equality criteria*) evaluation results did not manifest significant differences. Medians for C1 (2.8 and 3.5) and C7 (2.5 and 2.3) (see figs 4 and 5) were similar. It was expected that accepted proposals would have better quality documents, as well as better integration of equality aspects. In this case, however, values for C1 and C7 were unexpectedly low for accepted proposals. In the case of C6 (*Interdisciplinary aspects*), the significant difference triggers not because C6 is very good or excellent in accepted proposals (median 2.8), but because it fails, or it is poor in rejected proposals.

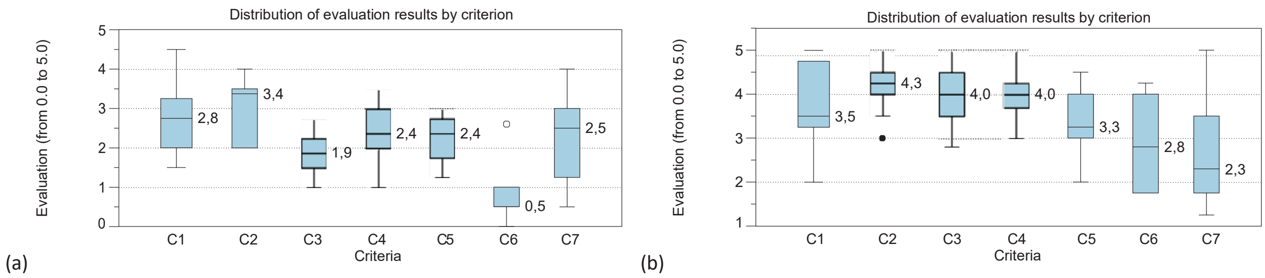

Figure 4: Criteria evaluation of rejected (a) and accepted (b) proposals.

Table 4: Mann-Whitney test P-value for each criterion between accepted and rejected proposals (Significant values in bold).

C1	C2	C3	C4	C5	C6	C7
0.143	**0.002**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.995

7 Discussion

The INGENIA program motivated students from both target populations (university and high- and vocational-school) to participate, with the majority of submissions (15 of 23) coming from university students. It appears that the training sessions that were provided did increase students' motivation to go out and find relevant problems in the local community but, unfortunately, roughly half of the proposals failed to propose viable and realistic solutions.

Quality of submissions by university students was not higher than those submitted by pre-university; there was no significant evidence of difference between proposals received from high school and vocational students and those received and accepted from university students. Regarding the funded proposals, there was not a statistically significant difference between proposals coming from pre-university students and ULL. Even though university students were required to be more independent (meaning that they have less experience to draw from), and pre-university students were more dependent and their teachers were more involved and had more overall experience, these facts didn't cause a significant difference in the quality of the accepted proposals. However, the authors cannot generalize this finding more broadly to future iterations of the project given that the sample size was not large enough, and it was a firstexperience.

Even though the program was presented to all students from all degrees, and the most relevant keynote of the Changemaker Day was presented by an engineer from MIT, the presence of engineering students participating in the program was marginal. The presence of a higher number of proposals from Tourism and Accounting and Finance degrees had to do with the involvement and active participation that academic staff has had with SDGs. In the Tourism, Accounting and Finance realm, involvement of the academic staff had a relevant effect in the involvement of students, and even though university students were required to be more independent than their HS/VS counterparts, building consciousness among the academic staff seems to be a key factor in the involvement of the institution with the SDGs.

As for program and evaluation design, the criteria used, the scoring process, and the threshold used to accept proposals were revealed to be effective because the significant differences in the majority of the criteria. However, the results revealed that students need more support to write quality documents and integrating interdisciplinary and equality aspects. Mentors should consider these weaknesses because students' enthusiasm was not enough to build a solid proposal to solve real-life problems linked with SDGs. Reinforcing mentoring and supporting the academic staff to improve their motivation and mentoring skills could be one of the keys to create impact through students. The authors believe the opportunity of real-life implementation via (1) appropriate funding and (2) mentor support was significant in the take-up and engagement by student populations. However, the delays and interference caused in the program due to the COVID pandemic —requiring students, facilitators, and mentors to work from home— is of interest and it is being studied.

The authors' future research will investigate the factors influencing student involvement in the initiative, and future iterations of the INGENIA program will integrate findings of this study.

8 Acknowledgement

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Student and staff experience of an interdisciplinary, multi-national co-curricular aerospace design project

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Abstract

The growth of the student numbers in the Department Mechanical and Aeronautical Engineering at the University of Pretoria, South Africa over the last 15 years has not seen equal growth in staff or support. The current curriculum based on the CDIO framework, in combination with the student numbers become resource expensive and ineffective in its attempt to increase students motivation for learning and to develop professional skills (communication, collaboration, innovation, creativity and project management). In order to explore ways to resolve this challenge an interdisciplinary, multi-national, vertically integrated engineering design project called AREND was developed as a co-curricular project.

Global collaboration in the aerospace industry is central to its existence and the AREND projects tries to replicate this structure with its international, intercultural and industry collaboration, spanning across 5 engineering disciplines. The paper describes the complex and ill-defined problem within the context of a technological solution for rhino poaching prevention as well as the sub-system breakdown into smaller diverse projects. The integration with the existing curriculum within the Department is described with the assessment criteria for each level from 2nd year to 4th year students and visiting international post graduate students.

Logistically the co-curricular structure has been successful and students can seamlessly enter and exit the project at any stage. And based on the experience of the staff members involved it seems the students are better prepared and more mature than those who have not worked within such a complex project and diverse group. There has been no interviews with either the staff or students to assess and determine the value of working in such complex and integrated projects across disciplines and year groups. This paper highlights some of the initial lessons and insights of practically implementing a PBL of this scale.

Keywords: co-curricular, project based learning, problem based learning, vertically integrated, interdisciplinary

Type of contribution: PBL best practice

1 Introduction

In order to address the shortage of engineering skills in South Africa, the School of Engineering at the University of Pretoria embarked on a growth strategy over the last 15 years. Although this endeavour was supported by creating additional teaching and research facilities for the School, the growth of the staff complement did not keep pace and very few venues were developed for Conceive, Design, Implement and Operate (CDIO) type activities.

The Department of Mechanical and Aeronautical Engineering follows the teaching framework of CDIO while stressing the importance of teaching engineering fundamentals in the context of real-world systems and products. The current curriculum in combination with the large student cohorts are resource expensive and can easily become ineffective. In addition, requirements for 4th industrial revolution transformation and globalisation of engineering curriculums intensifies the urgency to develop professional, communicative and innovative engineers for a diverse workplace. However, the risks of a full re-curriculation as well as the lack of time and staff to do so, leads staff to create and explore alternatives. One such alternative is the cross-disciplinary, multi-national, vertically integrated engineering design project called AREND which runs as a co-curricular project and problem based learning (PBL) program.

2 Theoretical/ pedagogical frameworks

Various institutions have implemented integrated PBL programs either on a co-curricular or curricular level. Some of the most notable efforts have been the Vertically Integrated Projects (VIP) Consortium a not-for-profit initiative birthed from the success of the VIP program at the Georgia Institute of Technology (Coyle et al, 2006; Abler et al., 2010; Coyle et al, 2014), the Integrated Engineering Program at University College London (UCL) (Fung, 2017) and Megaprojects based on global problems as formulated in the United Nations' 17 Sustainable Development Goals at Aalborg University, Denmark (Aalborg University, 2020).

The suitability of PBL in engineering education has been discussed in literature (Heitmann, 1996; Mills and Treagust, 2003; Perrenet et al., 2000; Kolmos, 1996; Edström and Kolmos, 2014; Guerra, 2017). Project and problem-based pedagogies both stem from active learning theory where the student is at the helm of knowledge creation with the lecturer acting as a guide and encourager, rather than an instructor. However, there is a distinction between project and problem-based learning. The descriptions in this paper are based on the influential work of Savery (2006).

Problem-based learning presents students with an ill-defined problem that is relevant to a real-world scenario. The problem is structured in such a way that collaboration and multidisciplinary knowledge will be necessary to solve the problem. Students collaboratively define the goals and objectives of solving the problem. They are then responsible for charting and executing their own learning path to achieve these goals. In the end their learning must be consolidated and applied to the resolution of the problem.

The primary difference between problem and project-based learning lies in the definition of the goal and the emphasis on correct procedure (Savery, 2006). In project-based learning, the goal is also shared, but there are specifications that define the product that would achieve the goal. This places boundaries on the solution exploration. Defining solution specifications also places more emphasis on the following correct procedures.

In the classroom, it is difficult to distinguish between purely project and purely problem-based approaches. Lehman *et al*. (2006) explain that within a learning project, students frequently encounter problems which create teachable moments. AREND is absolutely a blend of the two pedagogies. The overarching problem definition is stated as:

"*Team AREND will design a technological solution to aid Kruger National Park (KNP) rangers in the protection of black and white rhinos from poaching. The solution shall constitute, but not be limited to, an* *unmanned aircraft (18kg, 4.2m wingspan, cruise speed 20m/s, stall speed 15m/s) capable of conducting, efficient, quiet and remote surveillance of large park areas such as KNP. The drone shall be operable from a central base within KNP, have extended flight endurance (~120 min), and be able to detect/distinguish humans and animals with on-board sensors. Design modularity is encouraged*."

Working towards this goal has been a multi-year, multi-project journey. While the product of each project (such as the catapult launcher) has specifications and there is emphasis on the mechanical design process, many ill-defined problems emerge along the way.

3 Description of context

What started out in 2014 as a short-term student initiative aimed at entering the Wildlife Conservation UAV Challenge (www.wcUAVc.com) has grown into an ongoing co-curricular innovation project. The so-called AREND project was established as an international team of students at four universities on three continents. The original participating universities were: the University of Colorado (UC) Boulder, United States; the Helsinki Metropolia University of Applied Sciences, Finland; the University of Pretoria (UP), South Africa; and the University of Stuttgart (US), Germany. These four teams provided complimentary technical skills, while the Pretoria team had the additional contact to the Kruger National Park organization.

US had existing funding for collaboration projects, but the other partners did not. The team ran a kickstarter funding initiative to collect funding for the materials and sensors required by UP and CU. The funding was mainly to buy materials and build the drone which was part of the technological solution developed by the team.

The primary task that the UP team started with in 2014 was to develop the concept of operations based on information obtained from a wide variety of specialists, ranging from biologists to rangers to pilots, to understand the challenges and difficulties surrounding poaching prevention in the Kruger National Park. This gave the UP team the ability to set up a unique strategy and defined the specific design requirements for the drone. In 2014 the UP team consisted of two part time Mechanical and Aeronautical Engineering PhD students who were full time staff members in the department. They took the roles as project lead and design advisor. In addition there were 6 final year students who volunteered on the project. The competition, which originally unified the team never took place but, towards the end of the year a student from US, who designed and built the wing for the drone for his Masters degree, joined the team at UP for initial flight tests.

In 2015, the leadership of the project was moved to UP. In order to facilitate and assess student participation the project was embedded within PBL modules from 2nd year to 4th year level in Mechanical, Aeronautical, Electronic and Computer Engineering. The intention with the integration into curriculum was initially merely to have students spend dedicated time on the project and we had 9 students (one 4th year, four 3rd years, two 2nd years and 2 student volunteers) and 1 Master level student from UC. There was still participation from US to some degree but no formal student involvement took place during 2015.

The existing PBL modules UP has are: a 6 month capstone design module in the 4th year and a 1 year capstone research project in the 4th year. These are managed by individual staff members, each receiving 10-20 final year students per year. Both the project lead and design advisor of the team allocated some of their final year students working on these capstone projects to the drone and auxiliary systems. Conveniently these projects are then directly assessed on Engineering Council of South Africa (ECSA) level outcomes 3 (Engineering Design), 6 (Professional and technical communication) and 9 (Independent learning ability). Within the supervision of the project ECSA outcomes 8 (Individual, team and multidisciplinary work), 10 (Engineering professionalism) and 11 (Engineering Management) were also facilitated, but nor formally assessed.

The second set of PBL modules were the 2nd and 3rd year practical training modules where students, as part of the outcomes for an Engineering degree at the UP, must gain 240 hours of industrial experience. The aim is to develop insight on the practical application of engineering science in industry and the related human relationships and safety aspects. Supporting students to develop skills, an agreement was established with the Council of Scientific and Industrial Research (CSIR) to train them in composite design and manufacturing and airframe integration. After which each of these students are assigned to smaller design and manufacturing portions of the greater AREND team (Smith *et al.*, 2018). Figure 1 shows the specific structure of the University of Pretoria team and the interface with industry and international universities.

Finally international Master students are able to join the team for 6 month internships, completing their thesis requirements, gaining practical training experience and acting as deputy project managers in the local team.

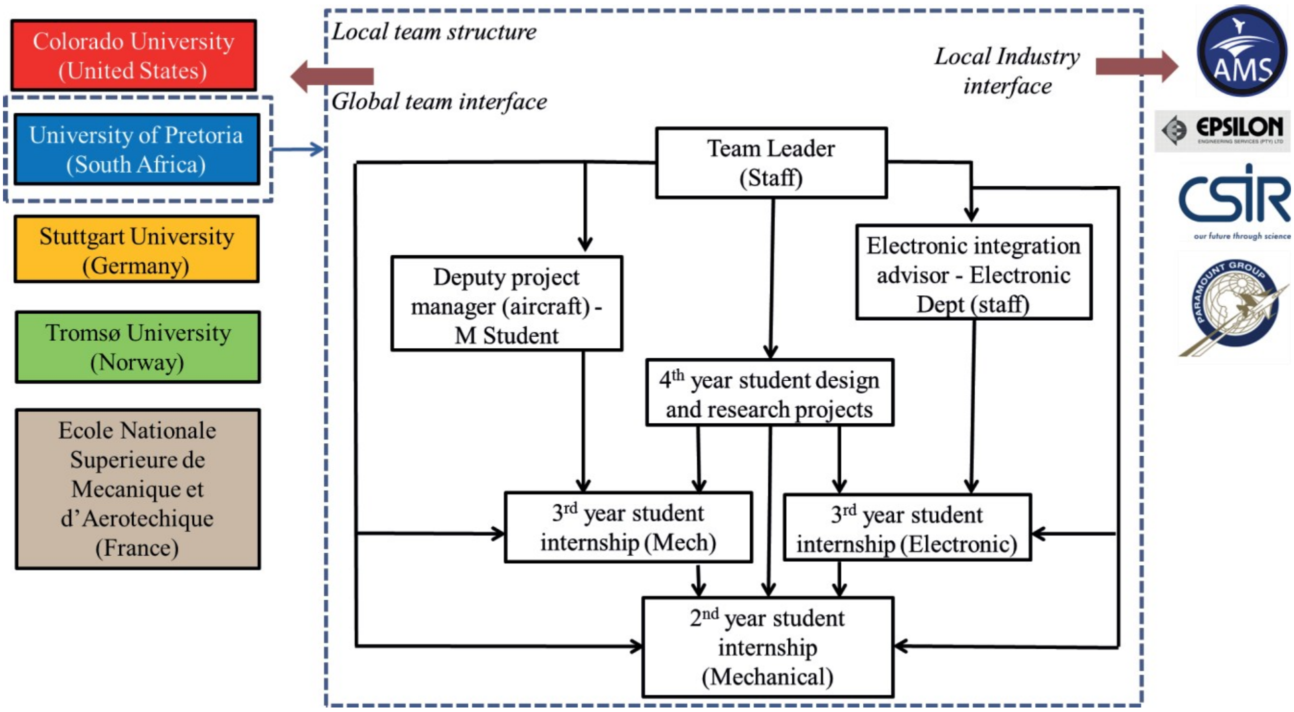

Figure 1: Local team structure and curriculum integration at University of Pretoria.

The project evolved into a co-curricular framework which incentives were to integrate development of innovative attitudes, cultivation of professional skills and facilitation of early cross-subject synthesis. To do so with as little as possible resources, but with a great impact on student experience. In addition these projects are aligned either with core research within the Department or with local industry to foster global awareness and civic responsiveness as part of a global collaboration amongst Universities in South Africa and abroad.

4 Co-curricular framework

Table 1 provides a brief summary of the five phases of AREND's evolution from 2014-2020.

Table 1: Five phases of co-curricular development in the AREND project at University of Pretoria.

Phase 1	2014	***Full international collaboration with three institutions and no co-curricular alignment.*** ▪ Four final year students working with 2 permanent staff members as volunteers

		at UP. ▪ Weekly engagements with international teams via online platforms. ▪ No formal task allocation to the UP students. ▪ Integration phase with US post graduate student visiting UP for first flight tests.
Phase 2	2015	***Reduced international collaboration with two institutions and pilot co-curricular alignment with PBL modules.*** ▪ Nine students working with 2 permanent staff members at UP, with projects embedded in 4 different existing PBL modules across three disciplines. Formal task allocations. ▪ Off-campus lab space to work on the drone with no lab assistants or support. ▪ Manufacturing training at the CSIR for students in their 2nd and 3rd year. ▪ Integration phases with CU post graduate student visiting for sensor integration and testing of the drone.
Phase 3	2016-2017	***Local industry involvement, flexible international collaboration and stronger co-curricular alignment.*** ▪ Sixteen students working with 1 permanent staff member at UP, projects embedded as in Phase 2. ▪ Two smaller sub-teams forms within the main team to develop sub-systems for launching and landing for the drone. ▪ First international undergraduate students internships on the project ▪ Three local drone companies engage with the team and offer a variety of 1-2 week internships for 2nd and 3rd year students to build capacity and skills within the team. ▪ Dedicated lab space provided for the team members on UP campus with machine lab training.
Phase 4	2018-2019	***Local industry involvement, flexible international collaboration and attempted integration onto the Vertically Integrated Projects (VIP) co-curricular platform.*** ▪ Nineteen students working with 1 permanent staff member at UP, projects embedded as in Phase 2. ▪ Local industry assist with legislation documentation and offer training on flight test safety procedures. ▪ Local industry internships remain. ▪ First 6 months Master thesis project internship from SU. ▪ Two new international undergraduate interns join the team. ▪ Senior students take leadership roles within the sub-teams and direct the course of the sub-systems with the project lead. ▪ First successful flight test with integrated system. ▪ Attempt to change team culture by integrating with the new VIP consortium initiative at UP. ▪ First student-defined final year research and design projects related to AREND in the 4th year. ▪ First industrial engineering students on the team.
Phase 5	2020	***Local industry involvement, flexible international collaboration and promotion of the learning pathway concept for co-curricular alignment.*** ▪ 23 students working with 1 permanent staff member at UP, projects embedded

		as in Phase 2. ▪ Two international 6 months Master thesis students from Germany and Norway on the team. ▪ Sub-teams are fully autonomous and report to the project lead rather than directed by the project lead. ▪ Local University collaboration with University of Cape Town. ▪ Multiple student defined projects for the final year capstone research and design module.

5 Results and reflections

One of the key features of the vertically integrated co-curricular framework is the scaffolding of project complexity based on level involvement. On a technical level students are assigned tasked based on the requirements for the PBL modules they are receiving credits on through the project. Although all students are required to go through an online training to have an overall understanding of the system and design decisions made in the past, their individual tasks are customized to suit their level. Second year students are involved with manufacturing training, designing for manufacturing and setting up CAD models and manufacturing parts for the various subsystems. Third year students are tasked with small design projects (example the housing for the battery packs in the drone, or development of the drone interface with the catapult) and in addition has to participate in organisational decisions and contribute to ideas regarding improvements. Fourth year students, design, build and test larger systems (catapult, emergency landing gear, gimbal etc) as part of their capstone project. Therefore it is possible for a student to start in the team as a manufacturer for a catapult system, to design subsystems for a greater system and in this experience gain enough understanding to choose their own capstone project based on a new improved design or technique. International Master students joining the team become deputy project managers, working closely with the team lead. Their projects are typically related to novel contributions surrounding the drone (redesign of a wing only configuration with optimised stability).

Students are able to stay in the project over consecutive years, giving students the ability to work with different junior and senior level students and encouraging peer-to-peer mentoring and learning. In this the students become a supervisory resource themselves, and over time the supervision role becomes more passive as the project becomes more student-centred in operation. The project also develops a level of communication skill when students have to relate basic and complex concepts to junior or new "non-experts" group members and communicate with others using a "common vocabulary". These skills are difficult to teach in a classroom set up without an authentic experiential learning process facilitated through a vertically integrated PBL and are essential for workplace needs and demands.

There were a couple of unforeseen difficulties during the various phases that had to be addressed and the lessons will be described in this section.

5.1 Experience with PBL and the integration thereof

PBL has been proven to develop a wide variety of competencies in engineering graduates. Some of these are self-efficacy, improved conceptual understanding, synthesis of information, ability to work in a team and reasoning skills (Dunlap 2005; Mills, 2009; Prince, 2004; Felder, 2006; Gavin, 2011; Dochy et al. 2003; Distlehorst et al. 2005). There are admitted shortcomings to the effectiveness of PBL pedagogies in engineering education. The major criticism against PBL in engineering education is that it is insufficient in developing all the required professional skills of an engineer (Heitmann, 1996; Mills and Treagust, 2003). While students educated in a PBL environment might be more motivated and demonstrate better communication and teamwork skills, they lack a deep understanding of engineering fundamentals (Mills and Treagust, 2003). To mitigate this shortcoming and to incentivise students, the AREND project is closely aligned to engineering curricula.

A design stream of modules is inherent in all Mechanical and Aeronautical Engineering (if not all engineering disciplines) and offers a simple avenue of vertical integration of PBL endeavours. Aligning PBL to a real-world problem (ill-defined) and finding the right modules to integrate was simpler than “managing” the PBL engagements. In Phase 1 and 2 the design advisor was very directive in terms of what exactly the problem is and what best practice would be to solve it, leaving very little scope for students to truly engage and grapple with the problem. They were also given allocated tasks without necessarily understanding the full context of the project. The design advisor prioritised “focus time to complete a workable” solution which in practice sounds good, but was found leaving students frustrated and unable to engage.

In Phases 3-5 there was no design advisor in the team. The sub-teams’ projects were allocated in a vague manner or developed by older students on the project out of perceived necessity or just curiosity. Design reviews (4 per year) were the only time students received input from the team lead or industry partners. It seemed that the absence of clear direction led to more self-direction, usually from older students but often from younger students who really want to work. During Phases 4 and 5, students developed multiple projects that don’t directly contribute to a solution for the existing objective but showed alternative routes that could potentially be pursued with equal success. The surge of drone use led students to conceive multiple alternatives uses of the drone and what design modifications could be relevant if such avenues were required.

Participating in the AREND project is not compulsory, which could mean that students entering the program already have a higher level of interest and need for engagement. It is not clear if this would be the case if the project was made compulsory. Generally the experience has been that students want to engage with the work only to the level that will allow them to pass well. In a school where typical class sizes range from 280 to 1300, AREND provides a great opportunity for hands-on experiential learning and the possibility to fail at the design objective or test, without failing a module. The modules the project is built into all assess “process” rather than final product and so if there is a workable product at the end it is perceived as a bonus to the team lead.

Students are frustrated by this since they are under the perception that their designs have to not only work but be a significant contribution to the project, but as soon as they understand that that is not the case they are able to create and experiment more freely. Fostering innovative attitudes (Trent and Smith, n.d.) and cultivating autonomy amongst students unlike any other existing style of project.

Facilitating an effective PBL initiative seems to be an art. Teaching at an institution where staff are trained to understand the learning outcomes and how to facilitate that is one part, but developing ill-defined relative design projects that adhere to existing module learning outcomes could be a challenge. There are various academics that do not have much experience in effective collaboration, multi-disciplinary engagement or knowledge about facilitating a space where students can be guided to develop traits associated with PBL. Careful consideration should be made before attempting a scaled up version. A group of 20-30 students are manageable, but 250-450 becomes a different playing field. In addition, if you lose student engagement and students only “work to pass” the value of PBL could belost.

5.2 Timelines, capacity and curriculum changes

During Phase 1, UP staff members (part-time PhD students) were responsible to keep to the international deadlines for the competition. The progress was quite slow, since their personal teaching load and PhD work took priority. They were basically also volunteers, with a slightly larger incentive to participate in the project. This became quite challenging since the deadlines for the competition was already embedded in the UC curriculum as a single graduate design module. US and Metropolia gave Master thesis topics related to their sub-projects allowing their schedule to be more flexible. This mismatch meant that UP members had to strain to keep up with the deadlines since all subsystems were dependent on the concept of operations and the aircraft configuration.

After Phase 1, it was clear that it was necessary to have a dedicated student team, who could work on the subsystems and small tasks and they somehow needed to be incentivized. Incentive translating to assessed and credited as part of their degree, because the volunteers had a true intention of contributing, but their eagerness waned as module and course deadlines approached. It was critical to ensure continuity of the project therefore the UP project manager and design advisor remained constant in the project.

Luckily the competition was cancelled, which relaxed the deadlines as the team decided to continue the project as an innovative design education project to provide a solution for the KNP. This gave UP the opportunity to schedule deadlines for the project to UP holiday periods at least until the project could be integrated into the curriculum in 2015 (Phase 2).

5.3 Management of expectations

A focus on ensuring interpersonal communication of individuals with challenges of cultural and language differences, did not include a focus on difference in engineering design approach which was the most challenging. International meetings driven and dictated to follow a specific routine design procedure did not align with this intention of producing a unique and innovative solution to the KNP. This had an impact on team morale and effective use of limited time (Smith *et al*., 2018).

The undergraduate students who volunteered during Phase 1 were quite disappointed, having hoped that they would actually get to build and fly the drone in the same year. Although in theory this would be possible, the level of design and innovation associated with the solution developed did not allow for quick off-the-shelf parts with easy integration. Even though their levels of enthusiasm was high, their real time involved in the project was dependent on their available space in a fully loaded final year curriculum. Their expectations were not expressed as volunteers and the project lead did not communicate any realistic plans for the activities which impacted team morale.

5.4 Unclear structures and roles within the project

In Phase 1, Metropolia never really understood their role in the team, it was unclear when and where their capabilities would be used. The initial idea was to develop a ground network alarm system to act as a trigger response for the UAV to be launched. They had two Master students volunteering on the team and although they were keen to work, the work package only became clear quite late, they offered a theoretical solution, but decided not to continue in 2015.

In order to mitigate these problems in Phase 2, members that volunteered or spent a short period on the project outside of the integrated PPBL received task memos derived from the main objectives by the lead designer. Through this all members of the group understood their responsibility and knew the overall objectives and role in the global team at all times. This also led to more motivated individuals and greater success in small manufacturing and integration challenges during the visits from the international Universities to UP (Smith et al, 2018). It is important to note that although these memos gave context and some background the design was still ill-defined without clear direction.

5.5 Available infrastructure and technical support

During Phase 1 and 2 both US and UP had no dedicated infrastructure that supported the project. There were also no dedicated technical support for these students. The context of the project is to contribute to a technological solution for the rhino poaching problem inspired local support from South African drone industry who offered mentorship and lab spaces for technical support was offered by the design advisor (Smith et al., 2018).

Phase 2 marked the integration into the UP curriculum, which had a couple of logistical challenges that had to be addressed. The lack of formal lab space and technical support was the most challenging for second year students who needs to gain experience in manufacturing. Even with the design advisors off-campus lab space there were no technicians to guide students to do the work. This caused major delays in manufacturing since students were at the mercy of the staff members to take time to go to the off-campus location and teach them the manufacturing process (Smith et al., 2018).

5.6 Project continuity and sustainability

After the project leads sabbatical from the project in 2016, Phase 3 had some challenges to update new students with the project vision and history. At the beginning of 2017, all previous students involved with the project graduated and only the project lead knew the history and trajectory of the project. This meant that a lot of time mentoring and guiding the new team was spent before they were able to work independently. The project lead position is still done on a volunteer basis, so the team also spent a lot of time reverse engineering what already exists, because contact time was limited. Some of the final years naturally acted as managers and mentors to these students, where others were overwhelmed by the responsibility and needed more supervision from the project lead.

Halfway through this phase new students entered and some old ones left, and the handover process was not well documented. Since the PBL modules linked to this project only required documentation of what was done, there was a lack of information on what the next phase should be. Students noticed this and took initiative to develop a documentation framework to help new members.

The increased number of students in Phase 3 and 4 and the establishment of smaller sub-team lead to project management challenges. Although the tasks were run through a global Google sheet to-do-list and all members could make sure that overlapping tasks were completed within the timeframe allocated, all members have different styles of engaging with the management and execution of projects. An additional industrial engineering student was recruited to set-up lab structures and communication structures between sub-projects.

The continuous challenge throughout the project was that the students had very limited time to spend on the project during the semester. The practical training PBL modules require students to work during their school breaks. A lot of meaningful progress were made during these periods, but the staff involved had no break in between semesters. Ideally the project would run during a semester, but with an overloaded curriculum progress were very slow if at all. Phase 4 attempted to solve this challenge by the migration onto the VIP structure and allocate working hours during the semester. However the working culture of the existing team struggled moving onto a new system they are not familiar with and had additional requirements (keep detailed design notebooks and complete peer assessment every 3 months).

Progress over the 6 months of the attempted integration were a lot slower as the team attempt to work in the semester and there is no bulk time to test and interface with industry. Three of the students working on the project as volunteers quit halfway into the semester due to heavy workloads of the curriculum, and the others were only sporadically active and useful. Although we have not had work periods in the University break, there has also been an associated decline in productivity and enthusiasm. Both the project lead and the students were too tied up in semester. So the integration into the VIP structure was temporarily abandoned.

5.7 Client-student interaction

In a real-world design scenario there are continual changes and challenges from different sources (client requirements, product viability, engineering method advances, manufacturing advances, etc.). The success of these projects lie as much in the students engineering skill and reasoning abilities as it does in the more professional skills like project, time and risk management and conflict resolution. These professional skills are difficult to formally teach but they are rather skills developed due to difficulties encountered within these project structures.

The team functioned fairly independently during phase 3 with no formal design advisor and little input from the project lead. The sub-system teams became very confident and each team had a natural leader arising who took control of the outputs and assigning of different tasks. The lack of management actually lead to better self-management. The first successful test flight took place in June 2018 after 4 consecutive failed attempts during April 2018. The failures inspired new smaller projects amongst the students and they worked towards a system and pre-flight check procedure that allowed for the eventual successful test. The mentorship here given by AMS was also invaluable.

Phase 4 included the creation of a wiki, which will address multiple challenges experienced in the project before. The problem of team hand overs and project history (once completed) will be reflected in this wiki and all new members can follow what particular progress on sub-systems were and where the project is moving next. This will potentially take the workload of the project lead and help new members coordinate themselves in the greater team and know who to link to for what specific tasks.

6 Conclusions

The project is a continuously evolving co-curricular experiment. At the end of each semester students and staff members involved reflect on the value and improvement of the project. The intention is to allow for more projects like AREND that are supported and gives other staff members experience in working with vertically integrated PBL groups. Real-time experience of staff members allows for a collective process of re-curriculation of a School with large cohorts and limited staff resource. In this paper we comment on the challenges at this small scale but also note the successes of the framework that was developed at UP for students and staff to interact with a vertically integrated PBL. The next phase of the project involved a more extensive study where students and staff are interviewed to establish whether the project was successful in its aim to foster innovative attitudes, integrate cross disciplinary understanding and cultivation professional skills.

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PBL, Industry and Entrepreneurship

Not in my backyard – Dealing with challenges of public participation in industrial and infrastructure projects in an engineering education

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Abstract

The course “Not in my backyard! Public participation in industrial and infrastructure projects” is located in the engineering faculties, but is aimed at students from all disciplines. It runs over the course of one semester and contains lectures from practitioners, a 2-day seminar and weekly PBL-sessions. The course deals with participation processes and conflicts in the planning and implementation of industrial and infrastructure projects like e.g. Wind turbines, gas pipelines or industrial production facilities. The challenge of finding appropriate solutions for the implementation of such projects is a socially relevant topic and is ideal for raising awareness for questions of public participation and sustainability whilst also strengthening competencies in data literacy and interdisciplinarity.

Within the framework provided by the VDI-Guideline 7000 (by the Association of German Engineers) questions of acceptance and acceptability as well as legal provisions in formal participation processes and the integration of early public participation in project development are dealt with. Contextual knowledge from the fields of environmental and technical research is imparted and success factors of accepted projects are presented.

The active engagement with roles and professions is fostered as well as dealing with online representations of knowledge (such as citizens’ initiative platforms or company websites). The aim is to promote interdisciplinary dialogue skills and a reflective attitude. Hence, the students are encouraged to change their perspective in many ways through different formats: working on the PBL cases in heterogeneous student groups, carrying out stakeholder analyses and participating in role play sessions in the 2-day seminar. Here the students explore different roles as stakeholder discussions are simulated, which are followed by rounds with feedback and reflection. The students are challenged to deal with complex situations, to test techniques and methods and to develop an attitude that enables participation and promotes joint solution finding.

Keywords: Cross disciplinary PBL, Interdisciplinarity, Sustainability, Public participation, Data literacy

Type of contribution: PBL best practice

1 Introduction

The ability to look beyond the limitations of one's own field of expertise and to think one's way repeatedly and readily into new processes and contexts, is of high relevance in the working life of engineers. Strengthening interdisciplinary teamwork is thus a relevant objective in engineering education. In times of globalization, digitalization and climate change, and the far-reaching transformative processes they entail, societies are being challenged globally. They are challenged in ways that can only be solved in comprehensive cooperation. For the educational sector the task arises to educate young people to be able and willing to such transdisciplinary cooperation.

Against this backdrop, the promotion of interdisciplinary cooperation was set as one objective of the ELLI project, which is funded by the German "Qualitätspakt Lehre", QPL (since 2011, the Federal Ministry of Education and Research (BMBF) has been supporting the improvement of study conditions and teaching quality at German universities with the federal-state program Quality Pact for Teaching). To achieve this goal, we set out to develop a lecture format that would reach across disciplinary and faculty boundaries while also aiming at a curricular formalization that would bring students of engineering into an interdisciplinary dialogue with students of humanities, social science, political science and economics. Over the run of the ELLI-project the teaching format has been planned, tested and further developed constantly for six years. It is now in its seventh run. This paper is organized as follows: Section 2 illustrates the challenges of interdisciplinarity and explains why we have chosen public participation as the main topic of the course. In section 3 we describe the concept behind this course and how the specific curricular integration was constitutive for the structural developing of the course. Section 4 provides an overview of the implementation and in section 5 we report and reflect on our experiences and explain the adjustments that were made as a result of these experiences.

2 The challenge of interdisciplinarity and public participation in engineering education

2.1 Interdisciplinary cooperation and interdisciplinary competency

The ability to contribute constructively in interdisciplinary teams and to help solve complex problems is a demand often put on university graduates of the 21st century. According to Lerch (2017), two central motives can be identified in the context of demands for interdisciplinarity, namely the handling of complexity as well as the wish for innovation. The relevance and challenges of interdisciplinary cooperation can be substantiated following Brandstädter & Sonntag (2014):

Relevance

- The subjects of research constantly increase in complexity
- One discipline alone cannot fully solve complexity
- High likelihood to find solutions to complex problems
- Increasing interest in subjects that cannot be assigned to a single discipline

Challenges

- Different disciplinary languages
- Different ways of thinking and points of view on the formulation of the problem
- Different methods
  (objective, interpretative, explorative, deductive, inductive, paradigmatic vs. pragmatic)
- Different objectives, values, motives

For the most part, questions of interdisciplinarity are discussed in a research context. There is a number of ways, forms and intensities to be differentiated (Lerch, 2017; Jungert, 2010). In the context of the teaching format we present in this text, the term interdisciplinarity is used following Jungert (2010) and the concept of a "composite interdisciplinarity":

- Urgent practical problems motivate the cooperation of different disciplines and compels the inclusion of different perspectives.
- Between these disciplines subject matters and methods usually do not overlap.

This entails that a relevant issue is "needed" to learn interdisciplinary cooperation and to put it into practice. The issue should be significant, relevant and complex in order to not only motivate interdisciplinary cooperation but also to justify the demanding work load it involves. Accordingly, a teaching format was developed that would apply challenges of inter- or transdisciplinary cooperation to a subject which refers to social issues. Students are in consequence asked to deal with the subject in terms of content and on a disciplinary level.

The desideratum of students being able to work well in heterogeneous teams does not yet determine what is to be understood under the term of "interdisciplinary competency" or rather which abilities and skills are specifically to be encouraged. The essential success factors for interdisciplinary cooperation are outlined concurrently as an open and appreciative attitudes of the actors, basic knowledge of other disciplines, cultures of professional socialization and methods, as well as social and personal competences, especially the ability of team work and communication (Vollmer, 2010; Brandstädter, 2018; Lerch, 2014). However, the question remains as to how interdisciplinary academic education can succeed or rather how we can introduce the encouragement of these abilities and attitudes in academic teaching and learning scenarios. Boix Mansilla describes "interdisciplinary learning" as a process in which "learners integrate information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines to craft products, explain phenomena, or solve problems, in ways that would have been unlikely through single-disciplinary means" (Boix Mansilla, 2010, S. 289). Problem and project-based teaching-learning-formats are mostly chosen as a method because implicitly they always address interdisciplinary competences. This problem-oriented approach is described as a key element in interdisciplinary teaching-learning settings that encourages the desired competency development. (Brassler & Dettmers, 2016; Lerch 2019)

2.2 Public participation as a subject in engineering education

The challenge of finding appropriate and sustainable solutions for the implementation of industrial and infrastructure projects, is highly relevant for today's society: "'Stuttgart 21' has become a symbol for protests against large-scale projects in Germany. The dispute over Stuttgart Central Station prompted 'Spiegel' in summer 2010 to create a cover story about the 'Against-Republic'. Especially infrastructure projects in the areas of Transport and Energy often encounter resistance from parts of the population [...]. Not infrequently, the conflict escalates, fronts harden, and there is hardly any factual exchange" (Brettschneider, 2011). In Germany, the implementation of infrastructure projects is even more so of importance in the context of the "The German Energiewende", as it not only means change on a policy level, but also includes the expansion of the electricity grid and the construction of plants and facilities for renewable energy production (above all wind power). Against this backdrop, a number of guidelines and toolboxes have been developed, including an array of recommendations concerning the kinds and forms of public participation in project planning processes (BS, 2013; BMVI, 2014; MWEI, 2012; SMBW, 2014). The Association of German Engineers (VDI) has extensively addressed the problem and chose it as their central theme for the German Engineers' Convention 2013: "In order to sustain and better the high quality of our infrastructure in the future, it is not sufficient for projects to meet technical, economic and legal criteria. In fact, the projects' use must also be recognized by society, and the citizens must take part in these projects. We have to face this huge challenge" (VDI, 2013). The VDI-Guideline 7000 for early public participation in industrial and infrastructure projects was devised through systematic analysis of successfully completed projects and in dialogue with experts for public participation, practitioners in private and public project developers, regional and federal authorities, civil society groups and associations (VDI, 2015). Based on the guideline's analyses, methods and tools, our course was conceptualized in cooperation with the VDI and has been carried out each summer term since 2014. Since the VDI is the biggest technical-scientific association in Germany and it is a representative speaker for engineers, being the leading technical standards-setting partner in economy and science. Not least, the cooperation with the VDI in this seminar facilitates a clear professional point of reference for prospective engineers and marks the importance of the topic for engineering students.

The VDI-Guideline 7000 tackles the challenge of implementing industrial and infrastructure projects in a sustainable and sustained manner on the operative level, however in the context of our seminar a number of questions still remain up for well-founded discussion concerning the normative and societal anchoring of these issues. We see a specific interrelatedness of the problem with Engineering Ethics and the Sustainable Development Goals (SDGs), which serve as one possible framework for reflection and discussion.

From an engineering ethics point of view, professional responsibility is a central concern since their profession requires engineers to deliver sound statements on technical feasibility, alternatives, risks etc. Not only is technical expertise demanded but it is as important to create the necessary trust for cooperation based on an ethically reflective and scientifically grounded statements and action (VDI, 2002). Moreover, there is a need to engage with the fact that those involved pursue different interests. A complex understanding of the term “trust” as a decisive precondition for developing and accepting joint solutions, is discussed systematically in VDI 7000. One of the central objectives and purposes of early and systematic public participation is “building and sustaining trust in actors and processes”. Demands such as transparency, credibility and respect are being addressed and retrieved from a place of a purely personal attitude. They are instead allocated to basic principles of early public participation which successful public participation should be based on (VDI 2015, S 11).

In conclusion, the challenge of finding sustainable and sustained solutions for the realization of industrial and infrastructure projects is well suited to address interdisciplinary competencies. Questions of cultures of communication and comprehensive cooperation are explicitly dealt with as a challenge in terms of content and are thus made accessible on different levels. The attitudes and competencies that are needed in order to be professionally successful coincide in many cases with success factors of interdisciplinary cooperation.

3 PBL-framework

As mentioned above, interdisciplinary formats of academic teaching usually deploy problem and project-based teaching and learning forms, because they address – to some degree – interdisciplinary competences. A concept of problem-oriented learning was chosen as the main format for this course, which is also referred to in literature as McMaster-, Maastricht- or 7- steps-method (Savery, 2006; Weber, 2007; Slemeyer, 2014; Berbuir et. al, 2014). An “operational definition” was provided by Barret:

“1) ***First*** students are presented with a problem

2) Students discuss the problem in a small group PBL tutorial. They clarify the facts of the case. They define what the problem is. They brainstorm ideas based on the prior knowledge. They identify what they need to learn to work on the problem, what they do not know (learning issues). They reason through the problem. They specify an action plan for working on the problem

3) Students engage in independent study on their learning issues outside the tutorial. This can include: library, databases, the web, resource people and observations

4) They come back to the PBL tutorial(s) sharing information, peer teaching and working together on the problem

5) They present their solution to the problem

6) They review what they have learned from working on the problem. All who participated in the process engage in self, peer and tutor review of the PBL process and reflections on each person's contribution to that process" (Barret, 2006)

The interdisciplinary course is designed to be attended by students of different disciplines as an optional subject. While the humanities' and social science' curricula allow students to choose from a wide range of subjects as optional subjects, the engineering curricula are much more restricted. In some disciplines there are two different types of optional subjects which are defined by content requirements. The formal rules for optional subjects are linked to the number of semester hours, the demanded workload, the examination format to be used and the corresponding assessment scheme. As a feasible workload for an interdisciplinary course emerged 150 to 180 hours for one semester. Amid the differing examination regulations and recognition practices of the different disciplines, it is necessary to offer two variants of the course. They do not differ concerning workload or content in the regular sessions but concerning the required assessments. In order to be awarded 6 instead of 5 ECTS-points students have to pass a written exam.

All in all, the performance assessment is established through three different elements:

1. Group presentations on the exam case: To finalize the course, students work on an exam PBL-case. Each group presents their PBL-process as well as the results in the form of a (public) presentation.
2. Seminar paper: Additionally, the students review and edit the research findings of their individual research question ("learning question") into a written documentation. This documentation serves as another element for assessment. In the text, students are asked to also lay out, in which form the results of their research has influenced the group discussions and how the topical discourse (which subsequently leads to recommendations on course of action, as presented by the group in the presentation of the exam case) within the group has formed.
3. Written exam: In a written exam, the basic principles of VDI guideline 7000 and key elements in participation processes are examined. The exam is mandatory for students of specific engineering disciplines, due to curricular requirements. For students of other subject areas, the exam is optional and entails the opportunity to gain six instead of the regular five ECTS-points for this course.

When discussing the concept of our course, it is important to note that Ruhr-University Bochum, as most other German universities, has no binding strategic guiding principle for the development of curricula. However, the university's teaching mission statement and the program for inquiry-based learning at Ruhr-University (RUB) are strong indicators to further establish and formalize inquiry-based learning in curricula. Against this backdrop, problem-based learning, which addresses many aspects of inquiry-based learning, may not be established in curricula as a guiding principle, but certainly there is considerable openness to such formats. Generally, adjustments to existing structures and traditions are necessary. As Kolmos and De Graaff write, "Owing to contextual conditions (cultural, national, institutional), specific curriculum models cannot be transferred directly between countries, as any PBL practice is a social construction and what might work in one cultural or institutional setting might not work in another" (Kolmos & De Graaff, 2014). For the context of our course it means that students are not experienced at problem-oriented learning and must thus be instructed intensively, especially in the beginning. In addition, the course deals with an interdisciplinary, complex topic and students come from different disciplines, which can lead to insecurities. For this reason, the PBL case processing is accompanied by a "classic" knowledge transfer in lecture format, which creates a uniform knowledge base for all participants for certain basic concepts. These lectures have the character of a lecture series in which internal and external experts give lectures on the topic. However, these lectures deliberately do not discuss exactly the issues arising from the PBL cases, but rather students receive information and insights into general issues in the context of public participation in the run of the semester.

4 Description of implementation

The course “Not in my backyard! Public participation in industrial and infrastructure projects” is aimed at students of all faculties and is recognized as an optional subject in different courses of study. The module sessions take place for one semester and are formally divided into a lecture and PBL-practice part as well as a 2-day seminar. The scope of the course is all in all four semester hours per week. Depending on type and scope of performance, students can earn five or six credit points (ECTS). In the introductory lectures a basic knowledge of public participation in Germany is presented by the instructor and aspects of social change, as well as questions of acceptance and acceptability are introduced. Subsequently, different external speakers are invited to provide insights into their vocational practice. These lectures take legal frameworks of formal and informal public participation, as well as aspects of regional planning into account and assume perspectives from project developers as well as environmental associations. The external lectures in 2019 e.g. dealt with “The structure of spatial planning in Germany”, “Involvement of nature conservation associations in planning and approval procedures” and the project example of “The gas-pipeline ZEELINK project”.

In the course "paper cases" are used, i.e. no real cases are worked on, but specially developed realistic case descriptions. Those cases present situations from planning and participation processes. A special emphasis is put on the course of action of the project developers. It is put up for discussion if and how they can react to vocal interests and challenges in the planning process of industrial and infrastructure projects. These cases are worked on by the students in groups. Participation in this course is limited to 24 students. To ensure a heterogeneous distribution, admission to the course takes subject quotas into account. After getting to know each other, the students divide themselves into 6 groups whilst considering that there should be no students of the same or related degree program in one group. There is no fixed tutor for each group, but 6 groups working in parallel are accompanied by 2 rotating tutors. The main PBL-tutor is the instructor, supported by a research assistant who has been trained in the support of PBL groups. The students receive a form for the 7-step method as well as material to structure and document the PBL process. All groups are asked to work with moderation cards and document their working process. As the work is done with small groups, only little moderation of the group work is needed. All students are given cards and pens and are asked to write their thoughts or aspects on a card and then to contribute these verbally and with the card also in writing to the group process. In the PBL work phases, the students spread out round the seminar room, which for this reason must be of sufficient size. Each group of four sits around one table. As a formal result of steps 1-5, the students have to record their problem analysis on a flipchart paper. For this purpose, the moderation cards created during the process before are structured and glued on. The learning questions must explicitly also be written on a card and are documented in this form. These rather strict formal requirements serve to give the students a grid in order to easier orient themselves in the new form of learning and teaching. These guidelines relieve the group process of formal discussions and serve to ensure that students really work and think with each other and not side by side.

During the semester, the students work on the PBL cases in a three-week-cycle. In the first the PBL case is handed out and the group then works on the case, finalizing the session with the deduction of “study questions” for further research. Each student individually researches these questions until the following week. The students upload their findings to the accompanying Moodle platform course. In the second week each student presents their findings to the other group members and discuss the new-found knowledge in relation to the hypothesis they developed the week before. Based on the extended basis of knowledge the students (re)evaluate the situation and develop recommendations for a course of action as well as possible solutions. This is followed up in the third week with a discussion and reflection in the course plenum. One after the other, each group presents their basic findings and solutions. Based on the comparison of the different approaches, the findings and specific characteristics are discussed and reflected upon together. In addition to the research tasks, derivate from the PBL cases, the students are asked at certain points to write a reflection of their work processes and to confront the challenges of a special teaching and learning situation (cf. Fig.1 below).

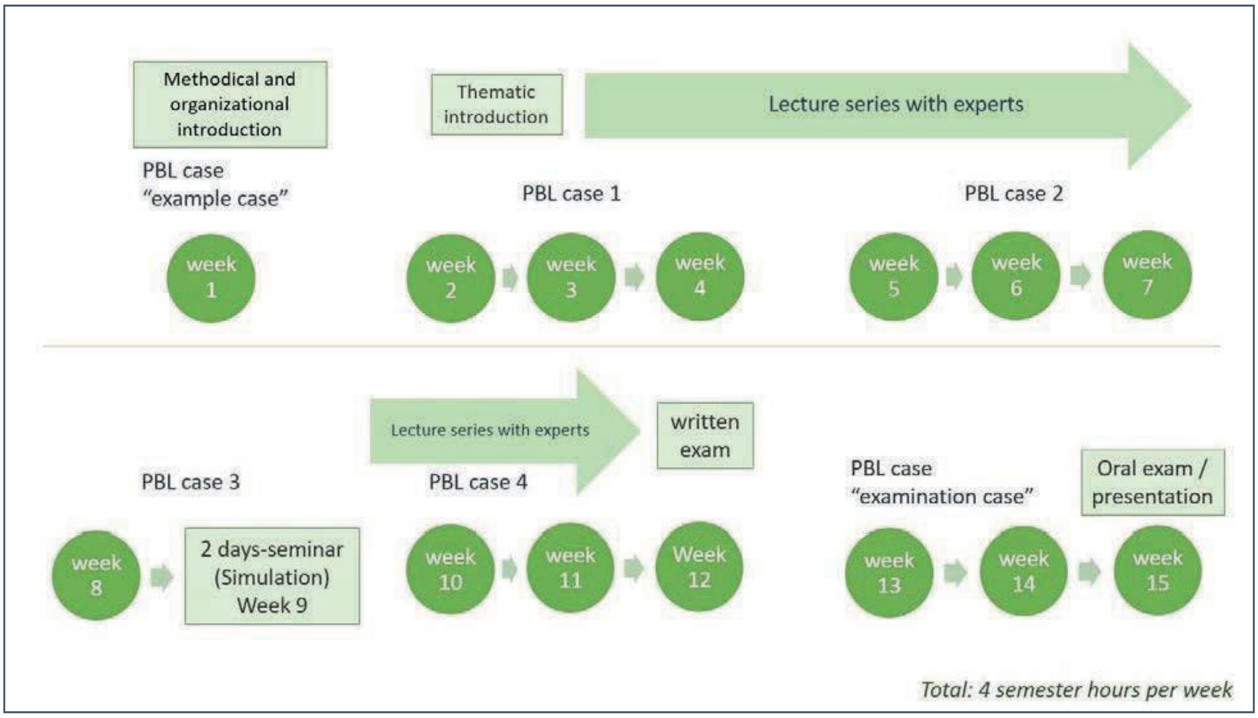

Fig. 1: Scheme of seminar structure

The problem-oriented approach is continued during the two-day seminar, the format also encompasses. This seminar takes place in the second half of the term and serves as an exemplary application of learned methods. It is also a deep dive into communication situations that occur in public participation. Based on three different PBL-cases, the cases are then further developed through contextual narration, supplemented by additional information and thus extended to a simulation scenario. Students must first apply certain content analysis methods (such as stakeholder and topic area analyses) to a case scenario. In a second step, the students should then plan a participation format, which is developed based on the results of the first step and the repertoire of methods of VDI 7000 previously dealt with in the course. In a third step, a participation format will be carried out as a simulated conversation (role play). The students are given specific roles for the scenarios, such as "project manager" or "affected citizen". They individually receive additional information for each role that substantiates the structure of the role. These instructions allow the groups to get into a prototypical communication situation. Communication patterns are analyzed, and reaction and intervention options are discussed in the joint reflection followed by each simulation unit.

5 Discussion of experiences and reflection of method

The course has been offered in the summer semester since 2014. Over the last six years there has been a great demand for this course from students of different disciplines and in different years of study. Most participants come from engineering disciplines (civil engineering, mechanical engineering, environmental technology and resource management, sales engineering and product management, logistics, industrial engineering). In addition, there are students from a wide range of subjects (geography, history, biology, philosophy as well as education, linguistics, social sciences and economics) with varying quotas. So far, a heterogeneous composition of disciplinary backgrounds could be realized in all student groups.

The overall assessment of the course in the evaluation was good to very good in all runs. For the majority of the participants, both the PBL method and the interdisciplinary cooperation were new experiences. The interdisciplinary cooperation is mostly emphasized as particularly positive and experienced as enriching by students. Based on the positive assessment, we deduce that the chosen format enables central learnings as students gain experience in PBL case work, joint discussion and reflection, and in the development of options for action and their presentation.

Students evaluate the two-days-seminar particularly positive in each case. For many students this is one of the rare opportunities to work intensively in groups over two days and to try out a different role. Especially the change of perspective, which is also emotionally carried out in the role plays of simulation, leads to special experiences. The students give each other differentiated and constructive feedback. The shared experiences let the students grow together as a course during this time. The role play format gives the students the opportunity to showcase and further develop their personal and social skills.

From the evaluations of the whole course in the follow-up feedback as well as from discussions during the course, it is clear that both the interdisciplinary approach and the unfamiliar teaching-learning form and method represent a new challenge, especially for students of classical engineering courses, which can sometimes also lead to uncertainty among students. It is important to be aware of possible uncertainties and to transfer them into constructive learning experiences. The instruction of work processes as well as the reflection of the topic and content-related work results play a central role in this process.

Both the introduction and the instruction of the PBL work phases were adapted over the last six runs of the course. In the first two runs the 7-Steps-Method was explained comprehensively and example cases from other research fields were presented and prototypical work results of a model case were presented. In past runs, there was an explanatory leaflet with a description of the individual steps and additionally a "protocol sheet" with a table representation of the steps and given guideline times of the processing. In this sheet the moderator of the group was supposed to document the time schedule of the processing. It served the purpose of becoming aware of the time required and, in case of large deviations, to then reflect and talk about why the deviation occurred and how this could be counteracted in the future. It turned out that this small-scale documentation of the work process, in addition to the documentation of the content of the work, was sometimes felt to be more burdensome than helpful. Therefore, the protocol sheet was dispensed with and the instructional information sheet was adapted. For this purpose, the steps were reduced to keywords, visualized with a pictogram and provided with a concrete instruction for documentation. During the first case studies in the course, the tutors then announce the time frames for processing the respective steps and control the processing procedure. Once the groups have made their experiences with the method, the groups take over the time control themselves and only in the case of recognizable difficulties is support provided by the tutors. This less formalized, at the beginning closely instructed and later more open approach has proven itself in practice.

Regarding the interdisciplinary subject matter and the associated uncertainties, the nature and scope of reflection on the results of the work was also changed. In the trial phase of the format, the PBL cases were processed in a two-week cycle. The research results were then presented and discussed within the groups. Over the course of the development of the module, the number of cases to be processed was reduced and the processing cycle of a PBL case was extended from two to three weeks (as shown in Fig. 2). This allowed the integration of a systematic, joint reflection with all students and a significant increase of the time it would take up. In the third week, the plenum will now discuss for each case what learning outcomes have been generated, which recommendations for action have been derived and how this can be placed in the context of the overall topic area.

This corresponds to the importance of reflection as it is regarded as a key to success in PBL setting: "Reflection is a precondition for problem-based learning, for setting up methodological frameworks, for being innovative and, on the meta-cognitive level, for being able to systematically improve individual and organisational learning processes" (Kolmos, Holgard, 2008).

Furthermore, it is very important that the structure and degree of complexity of the cases are well adapted to the methodological and thematic level of the students – as far as this is possible in an interdisciplinary group. Thus, at the beginning of the course, cases are initially less complex than the later cases.

The following figure summarizes the special challenges and chances in using the PBL method in an interdisciplinary course and with students who have no previous PBL experience.

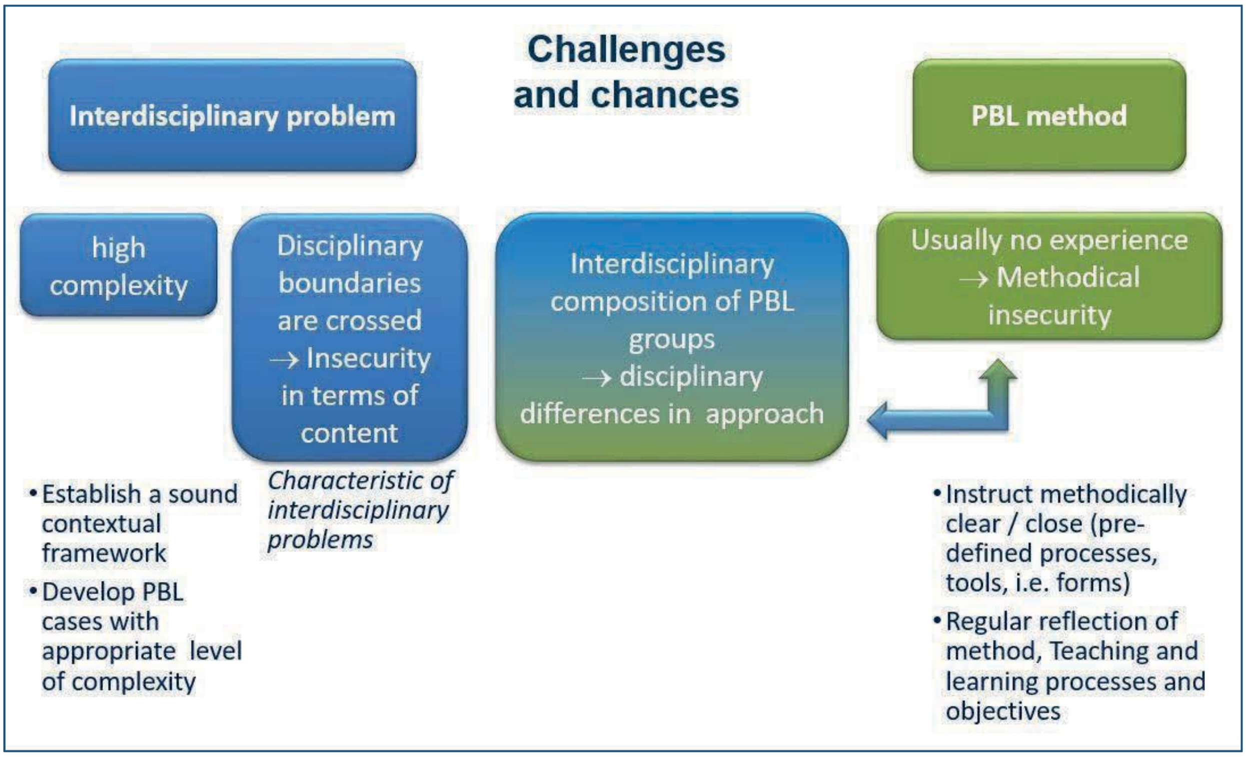

Fig. 2: Challenges and chances

Interdisciplinary problems are usually of high complexity and cross disciplinary boundaries, thus deliberately entailing a methodical insecurity. In order to make use of such problems in learning environments, it is important to establish a sound contextual and methodical framework. The PBL-Method is very useful to handle complex and usually “ill structured” problems. The to some degree open-ended results of the cases are both a challenge and a motivation. Especially for students of an engineering background who have not yet worked with the PBL method and who are usually trained in basic science subjects to work out “the right solution” for a specific pre-prepared learning task, dealing with this blurring of results initially means a great deal of uncertainty. It is therefore very important to instruct the method well so that experience and security can be gained here. Reflection is of particular importance in order to make the learning process and learning success tangible for the students. For the development of PBL cases in this course, this also means that the complexity and level of the cases must be adapted to the degree of experience of the students in using the method.

Following these reflections and based on our experience of the past six years, this course has proven itself to be an enriching experience for students and teachers alike in a stimulating teaching-learning setting.

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PBL to foster integration of company projects in engineering curricula – A case example

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Abstract

New trends and demands on engineering workplace call for more generic and employable competences such as communication, teamwork skills, problem-solving skills, lifelong learning, and digital literacy. Engineering education institutions are pushed to change and integrate more student-centred learning methodologies in their curriculum, such as problem-based, project-organised learning (PBL). PBL enables engineering students to develop knowledge and competences aforementioned. Furthermore, PBL provides opportunities to increase and diversify the collaboration between universities and industry, fostering innovation. Industry case examples have been proved to increase student interest and motivation. However, this paper describes a step forward on that industry-university collaboration level: involving companies in the project based learning experience. That is, involving the company in the tutoring and evaluation of a project developed by different groups of students. This could be understood as a dual training format more adequate for intermediate levels of bachelor degrees, when students are not mature enough to do a job in a company and get paid for it. This paper describes the experience of the Faculty of Engineering, Gipuzkoa (University of the Basque Country UPV/EHU, Spain) in supporting PBL integration in curriculum and in building industry collaboration. This paper descries the strategy Faculty of Engineering, Gipuzkoa (University of the Basque Country UPV/EHU, Spain) implemented with aim to develop a more innovative engineering education by re-organising their courses around projects and in collaboration with companies. Furthermore, the faculty's strategy is compressive, meaning that includes different strategies giving the students different learning experiences and contact with work place and employers in different moments of their education.

Keywords: Academic staff training, PBL, company projects, dual training.

Type of contribution: PBL best practice

1 Introduction

There are many attempts to reduce the gap between university and business, it is desired that the university prepare students adequately for their profession and it is hoped that business will be part of the solution. To this end, opportunities must be created for companies to get involved and work collaboratively with teachers, being part of the process and contributing to the quality of student work.

Companies give great added value to the academic work when they help teachers to create real tasks and projects. When students work on problems that matter, they get involved and make the problem their own, achieving better results. The key to a good University-Business-PBL relationship is to create a benchmark of what the university/university tutor will need from the company/company tutor, while at the same time allowing the company to increase their degree of involvement if they wish so.

This article analyses the implementation of Projects in Collaboration with Companies (PCCs) in the Civil Engineering Degree at the Faculty of Engineering in Gipuzkoa (San Sebastian, Spain) during the 2018/19 and 2019/20 academic years. Ten teachers and 30 students participated in PCCs projects. The teachers received specific training in the field of PBL and industry involvement to support the implementation of these projects.

1.1 Problem based, project organised learning (PBL): the theoretical framework

Traditionally, Problem Based Learning (PBL) has been defined as a teaching environment where problems lead to learning (Woods, 1996). This methodology was first used at the Faculty of Medicine of the University of McMaster (Canada) in the early 1970s. Usually, the acronym PBL is also used for Project Based Learning, to emphasize the word project, which refers to "a problem of longer duration, with more facets and which allows for the broad and in-depth exploration of the problem posed" (Jorgensen and Howard, 2000).

Throughout the literature on engineering education, it is evident that PBL should be considered as an option to be studied in the development of new or in the modification of existing engineering programs (Johnson and Ulseth, 2016). The extensive experience of Aalborg University (Kolmos et al., 2004), pioneer in the systematic implementation of this teaching model, the UNESCO reports (UNESCO, 2010; Beanland and Hadgraft, 2013), or the studies of Graham (2012) or Mills and Treagust (2003), which identify the PBL as a key element in the design and implementation of more innovative engineering programs, clearly demonstrate it.

As defined by Thomas (2000), projects are "complex tasks based on challenging problems that involve students in design, problem solving, decision making or research activities, and that provide the opportunity for students to work relatively autonomously for extended periods of time to complete realistic products or presentations”. It also establishes the five fundamental criteria that must be met in order to consider a methodology as PBL:

- Centrality. Projects are a fundamental part of the curriculum. That is, through them, students learn and apply fundamental concepts. They are not complementary exercises.

- They are problem-driven. The problem to be solved becomes the thread of the subject.

- Constructive research. The central activities of the project must be a difficulty and, to solve it, students must "build" new knowledge. Therefore, it is important to avoid the simple application of established recipes or solutions.

- Directed by the students. Projects should incorporate a good dose of student autonomy, freedom of choice and decision-making, unsupervised work and responsibility on the part of students. Although the teacher is always behind to support and guide the process, the leadership must be of the students.

- Realistic. Projects should convey a sense of reality to students, which makes them more involved and results better.

It seems natural, taking a further step, to add to these criteria a complementary one: collaboration with the company, which only reinforces the sense of reality of the project, giving a professional context to the academic work and reinforcing the motivation of the students by giving a justification to the need to acquire certain theoretical and practical knowledge.

Although some experiences already incorporate the collaboration with companies in the design and/or monitoring of teaching projects (Wang et al., 2012), there are no known experiences where such collaboration is part of the curriculum of the subjects. At Aalborg University (Denmark), the collaboration with companies is considered a key element of the project, being this collaboration included in their educational vision (Aalborg University, 2015):

“External organizations are familiar with the Aalborg model and cooperate actively with the University on students’ Project work.”

“The University’s collaboration with external organizations contributes to ensuring that students are able to work with contemporary issues that are relevant to their discipline or profession.”

In this context, with the objective of involving companies in student training, and with the limitations inherent in the structure of the Degrees involved, the Faculty of Engineering in Gipuzkoa proposes the Projects in Collaboration with Companies (PCCs).

1.2 Reducing the gap between University and Companies: the goal for engineering education at the Faculty of Engineering of Gipuzkoa

The Faculty of Engineering of Gipuzkoa located in San Sebastian (Spain) was founded in 1952 and was integrated into the recent public university, University of the Basque Country (UPV/EHU), in the 1970s. Today, the Faculty offers five B.Sc. degrees in Industrial Engineering (Mechanical, Electrical, Electronic, Renewable Energies and double degree Mechanical-Electronics), two B.Sc. degrees in Construction (Civil Engineering and Building Engineering) and four M.Sc. degrees.

Like many other higher education institutions, teaching methodologies have evolved greatly in recent decades, moving from a teacher-centred model to a more diverse and flexible student-centred model, with continuous evaluation and giving a major boost to teaching innovation. Specifically, with regard to the UPV/EHU's model of curricular development of teaching, it is based on the IKD Irakaskuntza Kooperatiboa eta Dinamikoa or Cooperative and Dynamic Teaching (www.ehu.eus/es/web/sae-helaz/ikd): a model that is unique, cooperative, multilingual and inclusive, and which emphasises that students should be the owners of their own learning and be trained in a comprehensive, flexible way that is adapted to the needs of society. The IKD model was unanimously approved by the UPV/EHU Governing Board in 2010 and developed in an operational manner in the Strategic Plan 2012-2017.

In addition, University-Business relations have been one of the priority axes of the UPV/EHU. Euskoiker, a non-profit organization, is a foundation, which has as its objective the development of relations between the UPV/EHU and society. Since 1979, it has managed numerous research projects, made strategic contacts and participated in several research presentation forums. As regards the Faculty of Engineering of Gipuzkoa, this University-Business relation is clearly reflected in the internships and the Bachelor Final Projects carried out in the industry. During the 2019-20 academic year 70% of the students did an internship in a company and more than 50% carried out their Final Project in companies, or external institutions.

This model is coherent with the priority axis University+Industry defined by the University Plan of the Basque Government 2019-2022. Likewise, the UPV/EHU makes this objective its own, establishing the following axis of action in the Strategic Plan 2018-21:

"To promote learning in real professional contexts through dual training in undergraduate and postgraduate studies, and the carrying out of internships, Bachelor final projects, Mater theses and doctoral theses in collaboration with the public administration, companies and social entities".

With all this, the Faculty of Engineering of Gipuzkoa has recently committed itself to an educational model based on university and industry collaboration. This model promotes the acquisition of skills by students, involves the industry in the training of students and brings the university closer to the reality of the professional and social worlds.

The educational model includes two different strategies to involve the companies in the engineering programmes and students' learning: training in the company and training in collaboration with the company. The first strategy refers to an internship in the company, which is the most common one employed in engineering education. However, this strategy has some disadvantages when is considered for intermediate courses of scientific-technical qualifications, i.e. courses that compose the curriculum and students take along their education. For this reason, the second strategy, collaboration with the company, is developed and it is what the Faculty of Engineering of Gipuzkoa calls Project in Collaboration with Companies (PCC).

The PCCs arise as an answer to the question: How can universities offer engineering students work place learning experiences throughout their education and in collaboration with companies? The PCC methodology is an adaptation of the Project based learning (PBL) methodology in which companies participate in the design, development and evaluation of the project. Their implementation requires redesigning various courses, which would integrate one or several projects and in which the company collaborates. The company role takes special emphasis in certain key moments of the project development, which are fundamental for strengthening the process of acquiring disciplinary knowledge and developing skills.

2 Design, implementation and evaluation of PCCs in Civil Engineering

Today the Degree in Civil Engineering is taught in more than 25 Faculties in Spain, most of which are going through a difficult time to attract students. The crisis in construction of 2008, the successive changes in denominations of the Degrees and the expansion of the offer in technological degrees have had a strong impact on enrolment. The Civil Engineering Faculties in Spain are joining forces to make their offer more attractive, to disseminate the profession of the civil engineer, as well as to promote the visibility and knowledge that society has about Civil Engineering. This is confirmed by the latest conference of directors of Civil Engineering Faculties where the need to work on some of the following has been highlighted:

- To enhance the visibility and knowledge that society has about Civil Engineering
- Strengthening the university-business relationship
- Increase the versatility of civil engineers through multidisciplinary profiles
- To promote the figure of the Civil Engineer in work fields such as BIM methodology, Sustainable Cities, Circular Economy, Energy Efficiency, Smart Cities data management, climate change mitigation, etc.
- Disseminate the qualifications and the profession in order to awaken new vocations

Given the aforementioned, the Faculty of Engineering in Gipuzkoa considered appropriate to pilot the PCCs model in Civil Engineering degrees, whereas it can address some of aspects highlighted namely

strengthening university-business relationships. Design, implementation and evaluation constitute the main three phases of the pilot process of PCCs in civil engineering.

2.1 Designing of PCCs for the Civil Engineering curricula

The Degree in Civil Engineering at the Faculty of Engineering in Gipuzkoa runs for 4 years and has 240 ECTS credits. These credits are divided into 66 basic training credits, 144 compulsory (72 common to the civil branch, 48 of specialty or specific technology and 24 of complementary subjects), 18 optional and 12 of Bachelor Final Project. The proposal of the Faculty of Engineering of Gipuzkoa establishes that the 30 credits that are given in the last semester of the degree (optional credits and Bachelor Final Project) are carried out in a company (internship in company, see table 1). Some students are already doing this in a self-managed way. It is therefore a matter of facilitating the process and clarifying the procedure.

However, the main novelty comes from the PCCs. These projects will be offered in 2nd, 3rd and 4th year courses, increasing their presence as the students move up the year. In 2nd year, students start with one course, in 3rd year they take PCCs in two courses and finally in 4th year they take PCCs in 4 courses. In total PCCs shall be implemented in 42ECTS (7 courses of 6 ECTS each).

Table 1: Distribution of ECTS given with industry collaboration and mechanism (Internship or PCC).

Modules	Total ECTS	ECTS with industry	Strategy
Training	66	0	-
Civil Branch Specific Technology Complementary	144	42 (29%)	PCC
Optional	18	18 (100%)	Internship
Bachelor Final Project	12	12 (100%)	

In the PCC methodology, the academic tutor (AT, university professor responsible for the subject) and the tutor in the company (CT, person in the company who collaborates in teaching the group of students) define a problem or project to be solved that becomes the thread of the subject. The problem must be realistic, adapted to the level of the course but sufficiently complex to allow all the teaching activities of the subject to be articulated around it.

The role of the CT is fundamental to guarantee the direct and updated contact with the professional reality. On the other hand, this way of working is based on a relationship of trust and fluidity between the two people responsible for teaching, the AT and the CT.

The process of adapting from a traditional teacher-centred methodology to a project-based, student-centred methodology involves analysing the content or the time spent (hours spent in and out of class) by the students. In addition, when there is a third party, the company, this adaptation requires a careful analysis of the role of the company tutor, the key moments in their collaboration or the way in which they interact with the students, among other factors.

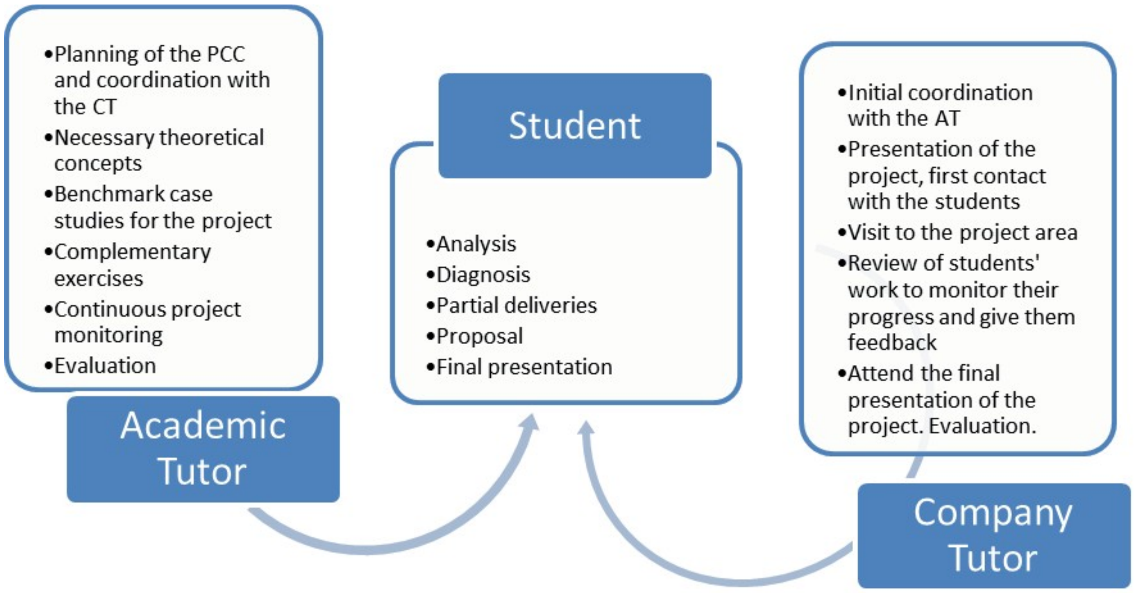


Figure 1: Participation scheme of the three PCC actors: academic tutor, student and company tutor. Source: Garmendia, Peñalba & Ostolaza (2019)

The first step is the choice of a typical project, which fits well with the subject and the skills that students must develop throughout the course. This is the key element for the success of the course. Ideally, from the point of view of student involvement and continuity, the course should be structured around a single project (although there may be several if necessary), thus making the project the main thread of the course. The project, having to solve this project (competence), is the reason why students must acquire certain knowledge. The project must be agreed with the company, so that the CT is clear about the skills and learning outcomes that students must acquire as a result of the project. Also, the AT can listen to what type of work the company partner does and problems that arise in that work, and together develop a driving question or statement for the project.

In addition, it is necessary to carefully design the programme of activities throughout the term. It should clearly establish the weekly tasks and activities of teachers and students, identifying deadlines, corrections, feedback, etc. Later, the development of the different activities and depending on the progress or difficulties encountered, this planning can be modified. In general, all PCCs follow the traditional structure in the elaboration of any project:

- Information, analysis and diagnosis.
- Proposal, comparison and choice of alternatives.
- Project development
- Conclusions

Depending on the location of the subject in the curriculum and the specific case, some phases may be more relevant than others. Thus, for example, in the second year projects, the first ones faced by the students, more emphasis is placed on the first two without having too much impact on the development of the final project; while in the third and even more so in the fourth year projects, the technical aspects of the development of the project are much more important, although this does not mean that the analysis and selection of alternatives are neglected.

Throughout a course based on the PCC, the class hours are dedicated to all kinds of activities of various kinds:

- Theoretical explanations by the responsible teachers or by the CT. They can be about some technical aspect needed for the project, about some instrumental aspect (representation, structure of documents, etc.), about some similar case to the project or about some general aspect of interest, even if it is not directly related to the project's subject.

- Workshop sessions in which the project is elaborated, the students' work is reviewed, it is discussed among students and/or with the teachers, etc. In these classes, teamwork is common.

- Scheduled revisions/corrections of the work, which usually include brief presentations or deliveries by the students. Teamwork is common but individual submissions may also be considered.

- Field visits to the project site or some other interesting place for the project.

The course is structured in different phases, usually divided into tasks related to the project. That is, it facilitates the resolution of a complex problem (project) by breaking it down into simpler problems (tasks), which in many cases may coincide with the phases of the project mentioned above (analysis, proposal, development). For each of the tasks, the theoretical content that the students will need is analyzed. This knowledge can be explained by the AT or CT or acquired through complementary tasks (for example, bibliographic consultations or Internet searches). Finally, the AT has to clearly identify in which part or task of the project each of the learning outcomes of the subject is worked on.

The CT can help to engage student interest and set the stage for a project from the very beginning. A visit to the Faculty or a field trip to the company location will pose the project challenge, kick off student inquiry, and provide an authentic “real-world” context for the project work that will follow. The role of the company in the initial phase of the presentation of the project to the students is crucial, since it gives veracity to the project, connects it with the professional reality of the students, and motivates and justifies the need to acquire the knowledge related to the subject.

Throughout the project, it will be necessary to establish at least one revision session of the students' work with the company tutor. Not only will partners be able to provide valuable feedback to students that is grounded in deep expertise, they may even be willing to share the critique and revision processes that they use in their own professional contexts. This revision is fundamental for the definition of the students' proposal and its adaptation to the reality of the project.

Finally, it is convenient that the students present a final synthesis of the project, especially if the course is organized around it. This final presentation summarizes the phases followed and includes the criteria used in the definition of the solution and the justification of the proposal and its final design. This is the most appropriate moment for the company tutor to make his last visit and collaborate in the evaluation of the projects. Knowing that they will be sharing their work with an audience of experts motivates students to create high quality work and validates the hard work that students put into their project development.

During this collaboration with the company, it is important to find a balance between the availability and level of involvement of the company tutor and the needs of the project. The timely but continued presence of the company tutor is essential to give the project a sense of reality and professional work and engage students. Moreover, the discussions with the company tutor during the workshops, as well as his comments during the students' presentations, enrich the learning of the students who receive feedback from someone other than their teacher, who has a less academic and more professional profile, usually more connected to the professional reality of the moment.

2.2 Implementing PCCs in the Civil Engineering curricula

The idea of introducing dual training or collaboration with the company in the curriculum of some of the degrees of the Faculty of Engineering of Gipuzkoa arose in the 2017/18 academic year. In this academic year, some experts in the field were invited and the teachers of the Faculty and the departments involved where invited to study the possibility of implementing this model in their subjects.

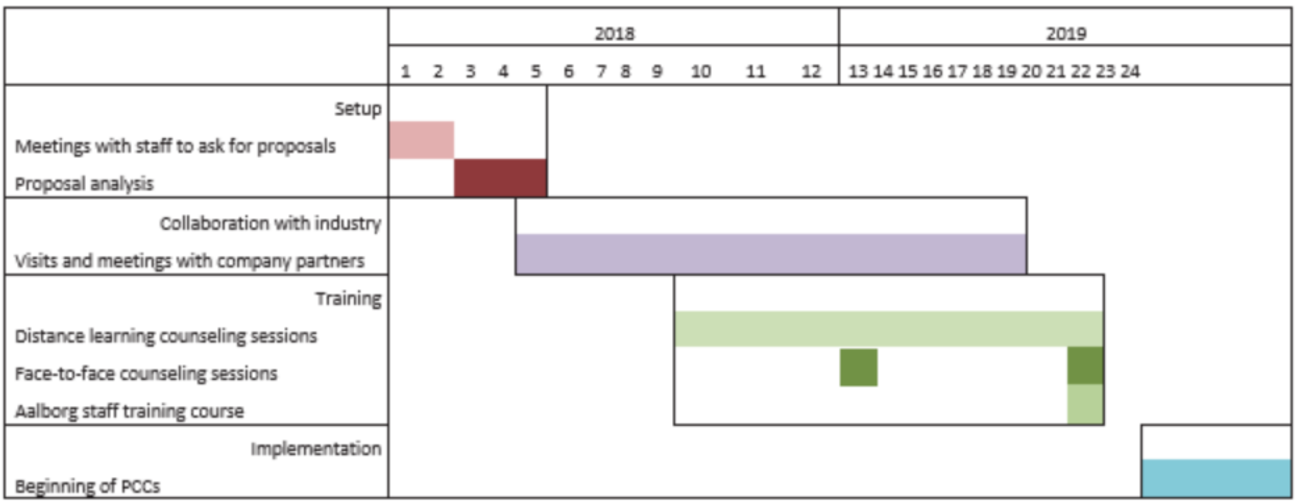
In the 2018/19 academic year, the Civil Engineering degree had a sufficient number of expressions of interest to start the process. During this academic year, three training and reflection sessions were held with a reference person in this field. The aim of the first three sessions was to tutor and help each teaching team on the best way to adapt their subject to the methodology of the PCC. Thus, these three sessions were distributed throughout the course (November, January and May) since at the end of May the EHU requires the departments to publish the teaching guides of the subjects, which must detail the teaching methodology to follow as well as the evaluation of the subject.

Besides, an agreement was established between the Aalborg UNESCO Centre for PBL in Engineering Science and Sustainability (Aalborg University, Denmark) and the Faculty of Engineering of Gipuzkoa. The overall goal was to inquiry the academic staff needs and expectations for pedagogical training and development in engineering education. Specifically, the aim was to plan, run, monitor and research a pedagogical intervention in shape of a crash course for academic staff at the Faculty of Engineering of Gipuzkoa. The staff-training course on "*PBL and integration of industry projects in curriculum*" was problem-oriented, exemplary and experiential, where participants developed basic understanding on PBL, PBL curriculum and course design, and integration of industry projects. It was held in July 2019.

With regard to the participation of companies, each department/teaching team identified the company or companies that could be most suitable to collaborate with the PCC. One of the criteria when selecting the company/entity was the existence of some previous contact with it. In some cases, where there was no previous contact, the principal of the Faculty established the first contact. Accordingly, throughout 2018/19, visits were made to the companies to agree or discuss the type of project in which they would work as well as the conditions of participation of the company tutor.

Finally in 2019/20 most of the courses started with the PCC methodology. In table 1 the timeline of the implementation process is shown.

Table 2: Timeline of PCCs implementation



2.3 Evaluating PCCs in Civil Engineering curricula

The evaluation of PCCs model focus in: (i) students' self-perception about their learning and degree, and (ii) course standard evaluation carried out to all courses carried out in a given semester.

Regarding students' self-perception about their learning and degree, two questionnaires were distributed: one before (pre-test questionnaire) and one after (post-test questionnaire) the winter semester of 2019/20. Questionnaires were distributed in class, so the number of responses is equal to the number of questionnaires distributed. At the beginning of the course 19 questionnaires were distributed and 12 at the end of the course. The difference of responses before and after the course is due to students who drop out the course. The scale used was in a 5-point scale. The aim of these questionnaires is to approach the student's view of the degree and to check whether this new teaching method significantly improves the student's perception of the degree. Figure 2 shows the results. In overall, results show that student's satisfaction with his or her training improves significantly. Students give a more positive evaluation of the complementary activities carried out, the acquisition of transversal skills, the applicability of what was studied as well as the contact with the professional world (Figure 2). In conclusion, the PCC model address two of highlighted priorities above, which are strengthening the university-business relationship, and promote the role civil engineering has in addressing social and professional challenges.

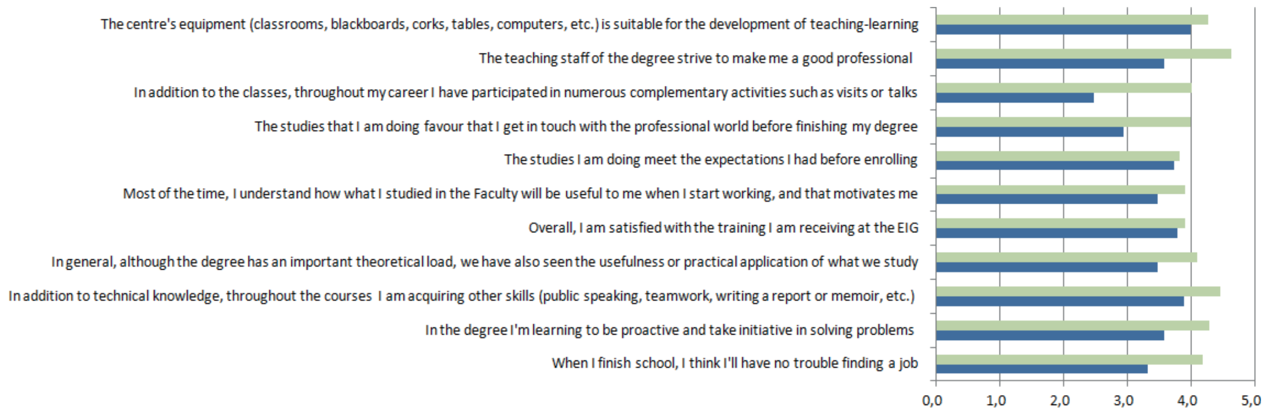


Figure 2: Students' self-perception about their learning and degree before (pre-test questionnaire in blue) (n=19) and after (post-test questionnaire in green) (n=12) the PCCs course.

Every semester students must answer a teacher's survey, which inquiry about their learning experiences by evaluating each one of the subjects they have studied. Figure 3 shows the comparison of the evaluation results of one of the subjects which has been adapted to PCC: the 2019/20 (PCC) and 2018/19 (non PCC). In 2018/19, there were 25 students enrolled in the course and 15 answered the survey, whilst in 2019/20, 19 students were enrolled and only 10 answered the survey. In this case, the results on the teaching given also improve significantly. All items improve except two (one is maintained, the other drops 0.1 points). The improvement is particularly noticeable in the questions related to student self-assessment (i.e. that students evaluate themselves better, in terms of the work done) and learning assessment, where it goes from an average of 2.8 to 3.5 out of 5 (Figure 3). In conclusion, students' have a better learning experience when in a course using PCC model. Furthermore, the results are also aligned with students' self-perception of degree and their development.

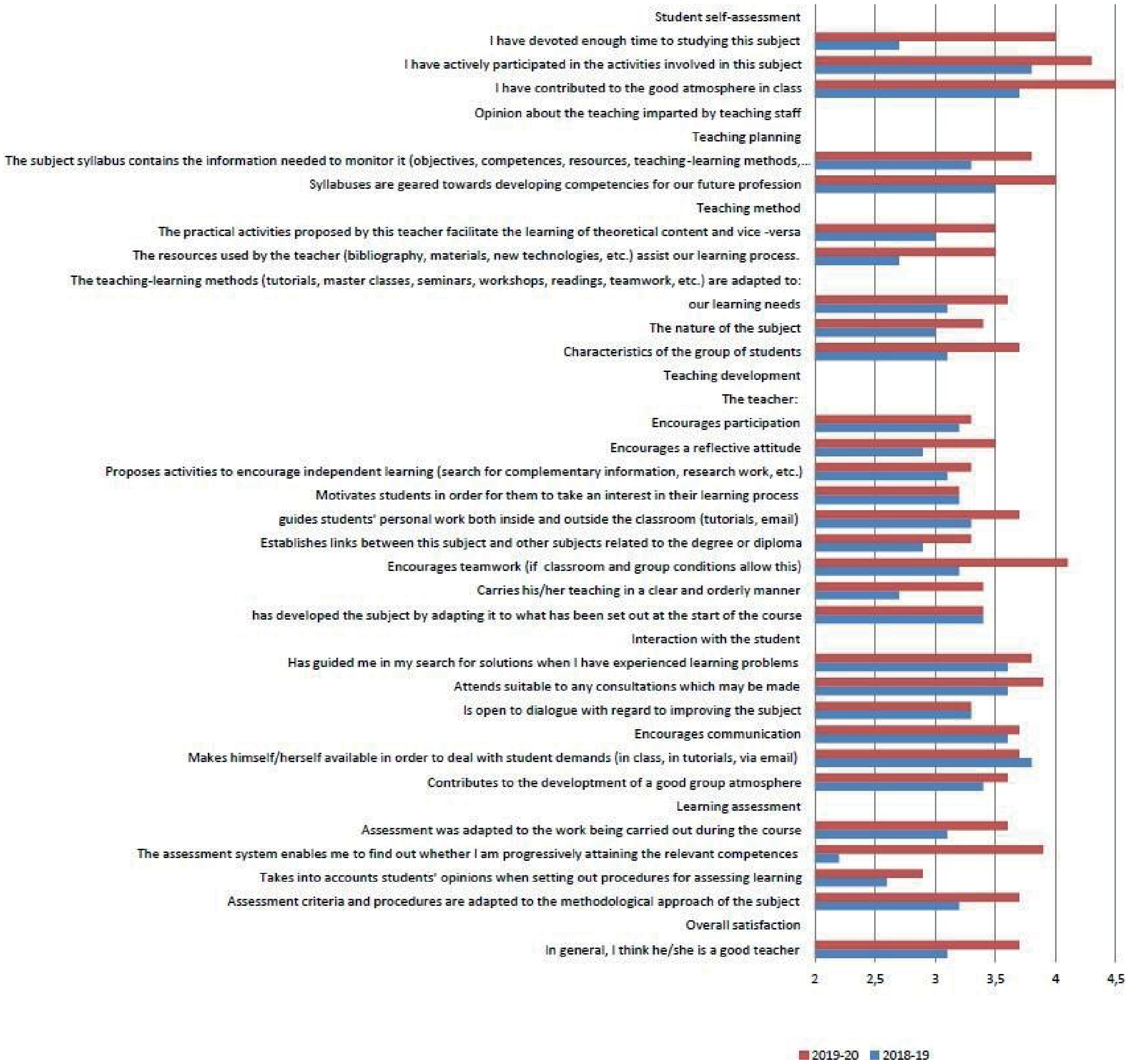


Figure 3: Course evaluation: comparison between non-PCC course (in blue), semester 2019/ 2020 (n=10), and PCC course (in red), semester 2019/20 (n=15).

3 Final reflections

This paper describes the strategy of the Faculty of Engineering, Gipuzkoa (University of the Basque Country UPV/EHU, Spain) implemented with aim of developing a more innovative engineering education by re-organising their courses around projects and in collaboration with companies. Furthermore, the Faculty's strategy is compressive, meaning that includes different strategies giving the students different learning experiences in contacting with work place and employers in different moments of their education. The PCC course model was evaluated using two questionnaires: one inquiring about students' self-perception of their learning and degree, and the standard course evaluation carried in all courses of the Faculty. In overall, students provide a positive evaluation of the course and the complementary activities that are integrated into and form part of the PCC model. They also are very satisfied with the development of their transversal skills and early contact with companies. Regarding the standard evaluation, when comparing with non-PCC courses (i.e. courses that do not follow the PCC model); students also provide a positive feedback. The results here presented are part of the piloting of PCC model in civil engineering curriculum; however, the results and experiences gathered enable to formulate some reflections to consider in the future development of the pedagogical model.

From a staff development perspective, it is needed more and focused pedagogical training to develop further their pedagogical skills and competences. The primary area of expertise of engineering educators is in engineering and therefore, we cannot expect that they have the suitable pedagogical knowledge and competences to start innovating and change their courses and practice towards more student-centred learning. The faculty has collaborate with Aalborg UNESCO Centre to provide earlier training on PBL, curriculum/ course design and collaboration with industry. However, the development needs to continue internally, not only to engage more academic staff towards a more systemic integration of PCC model, but to also develop community of practices for mutual support and learning.

From a learning perspective, the students' evaluation indicates we are moving the right direction in improving their learning experiences and create meaning to their development, namely development of transversal skills. The results also raise aspects to consider to move forward and take more research-based approach to change process, namely in which ways the PCC model increases students' motivation, or what are the implications in the attraction and retention of students in the engineering programmes following PCC model. No survey or questionnaire regarding the role of the company tutor on strengthening students' competence development was conducted, but definitively this will be taken it into account as future line of work.

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Democracy, Social progress and PBL

Industry Perspective on Project Based Learning –Comparing Chinese Engineering Managers *Overseas* with Chinese Engineering Managers *at Home*

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Abstract

It has been shown before that engineering competencies are developed by Project Based Learning (PjBL) and traditional learning to varying extents. Previous research has also shown that the cultural and socio-economic context of engineering managers influence their perspective on PjBL.

The purpose of this study is to identify the perspective of Chinese engineering managers working overseas and at home, in order to draw conclusions regarding PjBL in engineering programs of Higher Education Institutes (HEIs) and the contribution of PjBL to developing competencies for engineering work within a globalized world.

Questionnaire-based interview results are analysed using descriptive and inferential statistics (Wilcoxon and Mann Whitney U test).

The results show general agreement of the two groups of managers regarding the ranking of competencies developed by PjBL. Comparing between PjBL and traditional learning, managers at home perceive 14 and managers overseas perceive 2 out of 16 competency elements significantly better developed by PjBL than by traditional learning.

It is concluded that engineering educators and educational institutions should be encouraged by the positive perspective of Chinese engineering managers on PjBL. For further improvement of PjBL approaches, it is recommended to sufficiently include the theoretical basis of project tasks, mix students of diverse backgrounds, where possible, and for experiences in PjBL projects ensure sufficient learning facilitation when students apply established engineering methods, and encourage students to consider also alternative design standards.

Keywords: Project Based Learning, PjBL, manager perspective, engineering competencies, China

Type of contribution: PBL research

1 Introduction

It has been shown that perspectives on Problem Based Learning (PBL) are influenced by national culture (e.g. Walker *et al.*, 1996) and organizational culture of the educational institution (e.g. Camacho *et al.*, 2018). Industry is primarily concerned with the competencies of engineering graduates and the extent these competencies are developed in order to be utilized effectively in a professional context. However, sustainable education must consider industry expectations so that graduates are prepared for work in a globalized world.

Previous studies have shown that sets of competencies can be used to measure the effectiveness of PBL principles in general (Jaeger *et al.*, 2018) and to analyse specific PBL models (Ulseth and Johnson, 2015). Both, the effect of culture on PBL perception and the usability of competencies to analyse PBL perception, are also true for Project Based Learning (PjBL), a variant of PBL with an ill-defined project providing the starting point for the learning process.

For this study, Engineers Australia's sixteen competency elements for Engineering Technologists (EA, 2017) are used. These are similar to other sets of competencies such as the student outcomes of ABET (Abet.org, 2014) or the graduation requirements of the China Engineering Education Accreditation Association (Wu, 2015) which are adopted from the graduate attributes of the Washington Accord (IEA, 2013). They cover all essential skills identified in an earlier study (Nguyen, 1998) as distinct engineering competencies. A summary of these competency elements is shown in Table 1.

Table 1: Competency areas and elements.

COMPETENCY AREA / Competency Element
1. KNOWLEDGE AND SKILLS
1.1. Theory based understanding of the underpinning natural sciences
1.2. Conceptual understanding of mathematics, numerical analysis, statistics, etc.
1.3. In depth understanding of specialist knowledge areas
1.4. Discernment of current knowledge development, such as new methods and materials
1.5. Knowledge of contextual factors such as business, culture, laws, etc.
1.6. Understanding of the scope, principles, accountabilities of contemporary engineering
2. ENGINEERING APPLICATION ABILITY
2.1. Application of established engineering methods to problem solving
2.2. Application of engineering techniques, tools and resources
2.3. Application of systematic synthesis and design processes
2.4. Application of systematic approaches to the management of projects
3. PROFESSIONAL AND PERSONAL ATTRIBUTES
3.1. Ethical conduct and professional accountability
3.2. Effective oral and written communication
3.3. Creative, innovative and pro-active demeanour
3.4. Professional use and management of information
3.5. Orderly management of self and professional conduct
3.6. Effective team membership and team leadership

The purpose of this study is to identify the perspective of Chinese engineering managers within China (i.e. at home) and in the region of the Gulf Cooperation Council (GCC, i.e. abroad) on PjBL and traditional learning as suitable learning approaches to develop engineering competencies. Many Chinese engineering managers of Chinese firms are active in the GCC region (Pacheco and March, 2014) and projects such as the 'one belt, one road' initiative (Qian and Fulton, 2017) should lead to further activities in the GCC region and beyond. This provides an ideal situation to compare perspectives of managers originating from the same socio-cultural context, i.e. China, but assigned to projects in different settings with different challenges, i.e. overseas in the GCC region and at home in China. The findings allow important conclusions for engineering educators and engineering programs of Higher Education Institutions (HEI's) who aim to prepare the next generation of engineers for the challenges of a globalized world.

2 Research Questions and Methodology

The research questions for this study are as follows:

1) What is the perceived contribution of PjBL to the development of engineering competencies overseas and at home?

2) What is the perceived contribution of traditional learning to the development of engineering competencies as perceived by managers overseas and at home?

3) Is there a statistically significant difference between the perceived contribution of PjBL and the perceived contribution of traditional learning as perceived by managers overseas and managers at home?

4) Is there a statistically significant difference between the perceived contribution of PjBL overseas and the perceived contribution of PjBL at home?

5) Is there a statistically significant difference between the perceived contribution of traditional learning overseas and the perceived contribution of traditional learning at home?

In order to answer these questions, the following methodology has been applied. Questionnaire-based interviews have been carried out among engineering managers in China and in the GCC region. Only managers actively involved in supervision and leadership of Chinese engineers were approached, based on personal contacts of a total of 109 managers in China and 52 managers in the GCC region, resulting in a response rate of 100%. The questionnaire covered the sixteen elements of competency shown on Table 1, and the managers were asked to rate them using a 5-point Likert scale regarding, first, the contribution of PjBL in developing the competencies (very unimportant to very important) and, second, the contribution of traditional learning in developing these competencies (very satisfied to very unsatisfied). Prior to rating, the basic differences between PjBL and traditional learning were explained based on a schematic graphic taken from Jaeger *et al*. (2018), and it has been ensured that interviewees indicated understanding of the differences. Demographic data of the respondents has been collected and is shown in Table 2.

Table 2: Demographic data of respondents.

Variable	Answer Category	Engineering Managers			
		overseas (GCC)		at home (China)	
		#	%	#	%
Education					
	Bachelor	29	56	70	64
	Master	23	44	38	35
	Ph.D.	0	0	1	1
	Total Education	52	100	109	100
Position					
	Upper management	26	50	33	30
	Lower management	26	50	76	70
	Total Position	52	100	109	100
Industry					
	Petroleum	0	0	0	0
	Construction	49	94	108	99
	Manufacturing	2	4	1	1
	Telecommunication / Electrical	1	2	0	0
	Other	0	0	0	0
	Total Industry	52	100	109	100
Sector					
	Private	15	29	1	1
	Public	37	71	108	99
	Total Sector	52	100	109	100
Size of Organization					
	<10	1	2	0	0
	10-100	31	60	0	0
	>100	20	38	109	100
	Total Size of Organization	52	100	109	100
Industrial experience [average years]		7.1		10.1	

The analysis of data includes descriptive statistics to answer research questions one and two, as well as inferential statistics to answer questions three, four and five. To answer question three, the Wilcoxon test was chosen since the same group of respondents was evaluating two different aspects (i.e. the contribution of PjBL versus traditional learning), and for questions four and five, the Mann-Whitney U test was chosen since different groups of respondents (i.e. managers overseas and managers at home) were evaluating the same questions (Cohen *et al.*, 2011). Since both tests convert the scores to ranks, they do not require a normal distribution of scores, and the tests do not require similar sample sizes (e.g. Mann and Whitney, 1947). The level of significance, alpha, was set to 0.05 and the results are presented in the following section.

3 Results

The mean and standard deviation values are shown in Table 3 for Chinese engineering managers overseas and at home. Overseas, the contribution of PjBL ranges from "Theory based understanding…" (3.2) to "Creative, innovative and pro-active…" and "Effective team membership…" (3.9). At home, the contribution of PjBL ranges from "Theory based understanding…" (3.4) to "Effective team membership…" (4.7). overseas, the contribution of traditional learning of all competency elements is lower than the contribution of PjBL of these competency elements and ranges from "Theory based understanding…" and "Knowledge of contextual factors…" (3.1) to "Application of established engineering practices…", "Ethical conduct…" and "Effective team membership…" (3.5). At home, the contribution of traditional learning of all competency elements is lower than the contribution of PjBL – except “Theory based understanding…”, which is with a contribution of traditional learning of 3.6 higher than the contribution of PjBL (3.4). The contribution of traditional learning of the remaining competencies ranges from “In depth understanding…”, “Discernment of current knowledge…” and “Knowledge of contextual factors…” (3.0) to “Application of systematic design…” (3.7).

Table 3: Descriptive statistics (Mean, SD) of contribution of PjBL and contribution of traditional learning

Competency Element	Chinese Engineering Managers overseas				Chinese Engineering Managers at home			
	PjBL		trad		PjBL		trad	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.1. Theory based understanding…	3.2	1.2	3.1	1.1	3.4	1.0	3.6	0.9
1.2. Conceptual understanding of mathematics…	3.3	1.1	3.2	1.3	3.5	1.0	3.4	0.9
1.3. In depth understanding…	3.8	0.9	3.2	1.1	4.6	0.6	3.0	0.8
1.4. Discernment of current knowledge…	3.6	1.0	3.4	1.1	4.5	0.6	3.0	0.7
1.5. Knowledge of contextual factors…	3.5	1.1	3.1	1.4	4.3	0.7	3.0	0.7
1.6. Understanding of accountabilities…	3.5	1.1	3.3	1.1	4.2	0.7	3.1	0.7
2.1. Application of established engineering…	3.6	1.1	3.5	1.3	4.4	0.7	3.1	0.8
2.2. Application of engineering techniques…	3.5	1.1	3.4	1.4	4.3	0.7	3.2	0.7
2.3. Application of systematic design…	3.4	1.1	3.2	1.2	3.9	0.7	3.7	0.8
2.4. Application of systematic management…	3.4	1.1	3.3	1.1	4.1	0.7	3.4	0.7
3.1. Ethical conduct…	3.6	1.1	3.5	1.1	4.0	0.6	3.3	0.8
3.2. Effective oral and written communication…	3.6	1.2	3.4	1.2	4.4	0.6	3.5	0.7
3.3. Creative, innovative and pro-active…	3.9	1.0	3.4	1.1	4.5	0.7	3.2	1.0
3.4. Professional use of information…	3.7	1.0	3.3	1.1	4.1	0.6	3.3	0.7
3.5. Orderly management of self…	3.6	1.2	3.3	1.3	4.3	0.6	3.3	0.7
3.6. Effective team membership…	3.9	1.1	3.5	1.3	4.7	0.6	3.5	0.7

In order to facilitate interpretation of the data (see discussion section below), the competency elements have been ranked for both, overseas and at home, first, regarding the contribution of PjBL of competency elements (Table 4) and, secondly, regarding the contribution of traditional learning of these competency elements (Table 5).

Table 4: Ranking of competencies by contribution of **PjBL** (most important: green, to least important: orange).

Rank #	overseas	at home
1	3.3. Creative, innovative and pro-active…	3.6. Effective team membership…
2	3.6. Effective team membership…	1.3. In depth understanding…
3	1.3. In depth understanding…	3.3. Creative, innovative and pro-active…
4	3.4. Professional use of information…	1.4. Discernment of current knowledge…
5	2.1. Application of established engineering…	2.1. Application of established engineering…
6	3.5. Orderly management of self…	3.2. Effective oral and written communication…
7	1.4. Discernment of current knowledge…	3.5. Orderly management of self…
8	3.1. Ethical conduct…	2.2. Application of engineering techniques…
9	3.2. Effective oral and written communication…	1.5. Knowledge of contextual factors…
10	1.5. Knowledge of contextual factors…	1.6. Understanding of accountabilities…
11	2.2. Application of engineering techniques…	3.4. Professional use of information…
12	1.6. Understanding of accountabilities…	2.4. Application of systematic management…
13	2.4. Application of systematic management…	3.1. Ethical conduct…
14	2.3. Application of systematic design…	2.3. Application of systematic design…
15	1.2. Understanding of mathematics…	1.2. Understanding of mathematics…
16	1.1. Theory based understanding…	1.1. Theory based understanding…

Table 5: Ranking of competencies by contribution of **traditional learning** (most important to least important).

Rank #	overseas	at home
1	3.6. Effective team membership…	2.3. Application of systematic design…
2	3.1. Ethical conduct…	1.1. Theory based understanding…
3	2.1. Application of established engineering…	3.2. Effective oral and written communication…
4	3.2. Effective oral and written communication…	3.6. Effective team membership…
5	2.2. Application of engineering techniques…	2.4. Application of systematic management…
6	3.3. Creative, innovative and pro-active…	1.2. Understanding of mathematics…
7	1.4. Discernment of current knowledge…	3.1. Ethical conduct…
8	1.6. Understanding of accountabilities…	3.4. Professional use of information…
9	3.4. Professional use of information…	3.5. Orderly management of self…
10	3.5. Orderly management of self…	2.2. Application of engineering techniques…
11	2.4. Application of systematic management…	3.3. Creative, innovative and pro-active…
12	2.3. Application of systematic design…	2.1. Application of established engineering…
13	1.2. Understanding of mathematics…	1.6. Understanding of accountabilities…
14	1.3. In depth understanding…	1.4. Discernment of current knowledge…
15	1.1. Theory based understanding…	1.5. Knowledge of contextual factors…
16	1.5. Knowledge of contextual factors…	1.3. In depth understanding…

The significance of the difference between contribution of PjBL and contribution of traditional learning was further analysed for both situations (i.e. overseas and at home) and the results are shown in Table 6 for "overseas" and Table 7 for "at home". For "overseas" (Table 6), the contribution of PjBL is significantly higher than the contribution of traditional learning only for the competency elements "In depth understanding…" and "Creative, innovative and pro-active…". For "at home" (Table 7), the contribution of PjBL is significantly higher than traditional learning for all competency elements except for "Theory based understanding…" and "Conceptual understanding of mathematics…".

Table 6: Difference between contribution of PjBL versus traditional learning – **overseas** (significant difference: blue)

Competency Element	PjBL		trad		Wilcoxon	
	Median	SD	Median	SD	Z	*p*
1.1. Theory based understanding…	3.5	1.2	3.0	1.1	0.679	0.497
1.2. Conceptual understanding of mathematics…	3.0	1.1	3.0	1.3	0.283	0.777
1.3. In depth understanding…	4.0	0.9	3.0	1.1	2.711	0.007
1.4. Discernment of current knowledge…	4.0	1.0	3.0	1.1	1.219	0.223
1.5. Knowledge of contextual factors…	4.0	1.1	3.0	1.4	1.557	0.119
1.6. Understanding of accountabilities…	4.0	1.1	3.0	1.1	0.689	0.491
2.1. Application of established engineering…	4.0	1.1	4.0	1.3	0.507	0.612
2.2. Application of engineering techniques…	3.0	1.1	4.0	1.4	-0.111	0.912
2.3. Application of systematic design…	4.0	1.1	3.0	1.2	0.618	0.537
2.4. Application of systematic management…	4.0	1.1	3.0	1.1	0.819	0.413
3.1. Ethical conduct…	4.0	1.1	3.0	1.1	0.728	0.467
3.2. Effective oral and written communication…	4.0	1.2	3.5	1.2	0.579	0.563
3.3. Creative, innovative and pro-active…	4.0	1.0	3.0	1.1	2.295	0.022
3.4. Professional use of information…	4.0	1.0	3.0	1.1	1.612	0.107
3.5. Orderly management of self…	4.0	1.2	4.0	1.3	1.173	0.241
3.6. Effective team membership…	4.0	1.1	4.0	1.3	1.271	0.204

Table 7: Difference between contribution of PjBL versus traditional learning -- **at home** (significant difference: blue)

Competency Element	PjBL		trad		Wilcoxon	
	Median	SD	Median	SD	Z	*p*
1.1. Theory based understanding…	3	1.0	3	0.9	-1.066	0.286
1.2. Conceptual understanding of mathematics…	4	1.0	3	0.9	1.169	0.242
1.3. In depth understanding…	5	0.6	3	0.8	11.007	0.000
1.4. Discernment of current knowledge…	5	0.6	3	0.7	10.666	0.000
1.5. Knowledge of contextual factors…	4	0.7	3	0.7	10.245	0.000
1.6. Understanding of accountabilities…	4	0.7	3	0.7	8.850	0.000
2.1. Application of established engineering…	5	0.7	3	0.8	9.746	0.000
2.2. Application of engineering techniques…	4	0.7	3	0.7	9.068	0.000
2.3. Application of systematic design…	4	0.7	4	0.8	2.180	0.029
2.4. Application of systematic management…	4	0.7	3	0.7	5.729	0.000
3.1. Ethical conduct…	4	0.6	3	0.8	6.584	0.000
3.2. Effective oral and written communication…	4	0.6	4	0.7	7.411	0.000
3.3. Creative, innovative and pro-active…	5	0.7	3	1.0	8.953	0.000
3.4. Professional use of information…	4	0.6	3	0.7	7.484	0.000
3.5. Orderly management of self…	4	0.6	3	0.7	9.053	0.000
3.6. Effective team membership…	5	0.6	3	0.7	9.516	0.000

The significance of difference between overseas and at home regarding the contribution of PjBL has been further analysed and results are presented in Table 8. Two competency elements did not show a significant difference, namely, "Theory based understanding…" and "Conceptual understanding of mathematics…". Consequently, these differences will not be interpreted in the discussion section below. The contribution of PjBL of all significant different competency elements is higher at home than overseas.

Table 8: Difference between overseas and at home using Mann Whitney U test – **PjBL** (significant difference: blue)

Competency Element	overseas		at home		MWU test		
	Md.	SD	Md.	SD	U	Z	*p*
1.1. Theory based understanding…	3.5	1.2	3	1.0	2734.5	0.35789	.71884
1.2. Conceptual understanding of mathematics…	3.0	1.1	4	1.0	2522.5	1.12429	.26272
1.3. In depth understanding…	4.0	0.9	5	0.6	1469.5	4.93097	< .00001
1.4. Discernment of current knowledge…	4.0	1.0	5	0.6	1460	4.96532	< .00001
1.5. Knowledge of contextual factors…	4.0	1.1	4	0.7	1738.5	3.95852	.00008
1.6. Understanding of accountabilities…	4.0	1.1	4	0.7	1810.5	3.69823	.00022
2.1. Application of established engineering…	4.0	1.1	5	0.7	1594	4.48089	< .00001
2.2. Application of engineering techniques…	3.0	1.1	4	0.7	1559	4.60742	< .00001
2.3. Application of systematic design…	4.0	1.1	4	0.7	1964	3.14331	.00168
2.4. Application of systematic management…	4.0	1.1	4	0.7	1836.5	3.60424	.00032
3.1. Ethical conduct…	4.0	1.1	4	0.6	2278.5	2.00637	.04444
3.2. Effective oral and written communication…	4.0	1.2	4	0.6	1630.5	4.34894	< .00001
3.3. Creative, innovative and pro-active…	4.0	1.0	5	0.7	1869	3.48675	.00048
3.4. Professional use of information…	4.0	1.0	4	0.6	2142.5	2.49802	.01242
3.5. Orderly management of self…	4.0	1.2	4	0.6	1918	3.30961	.00094
3.6. Effective team membership…	4.0	1.1	5	0.6	1464.5	4.94905	< .00001

Regarding the contribution of traditional learning, Table 9 presents the significance of difference between overseas and at home. All competency elements are not significantly different, except three elements, namely, "Discernment of current knowledge…" (at home > overseas), "Application of established engineering…" (at home < overseas) and "Application of systematic design…" (at home > overseas).

Table 9: Difference between overseas and at home using Mann Whitney U test – **traditional learning**. (significant difference: blue)

COMPETENCY AREA Competency Element	overseas		at home		MWU test		
	Md.	SD	Md.	SD	U	Z	*p*
1.1. Theory based understanding…	3.0	1.1	3	0.9	2290.5	1.96299	.05
1.2. Conceptual understanding of mathematics…	3.0	1.3	3	0.9	2671.5	0.58564	.5552
1.3. In depth understanding…	3.0	1.1	3	0.8	2381	-1.63582	.101
1.4. Discernment of current knowledge…	3.0	1.1	3	0.7	2269.5	-2.03891	.04136
1.5. Knowledge of contextual factors…	3.0	1.4	3	0.7	2673	-0.58022	.56192
1.6. Understanding of accountabilities…	3.0	1.1	3	0.7	2305.5	-1.90876	.05614
2.1. Application of established engineering…	4.0	1.3	3	0.8	2249	-2.11302	.03486
2.2. Application of engineering techniques…	4.0	1.4	3	0.7	2297	-1.93949	.05238
2.3. Application of systematic design…	3.0	1.2	4	0.8	2188	2.33354	.0198
2.4. Application of systematic management…	3.0	1.1	3	0.7	2589.5	0.88208	.37886
3.1. Ethical conduct…	3.0	1.1	3	0.8	2520	-1.13333	.25848
3.2. Effective oral and written communication…	3.5	1.2	4	0.7	2750.5	0.30005	.76418
3.3. Creative, innovative and pro-active…	3.0	1.1	3	1.0	2462.5	-1.3412	.18024
3.4. Professional use of information…	3.0	1.1	3	0.7	2701.5	-0.47719	.63122
3.5. Orderly management of self…	4.0	1.3	3	0.7	2574	-0.93811	.34722
3.6. Effective team membership…	4.0	1.3	3	0.7	2615	-0.7899	.42952

The above results will be further discussed and interpreted in the following section.

4 Discussion

The first research question is related to the contribution of PjBL to the development of engineering competencies as perceived by managers overseas and at home. The ranking of competency elements by contribution of PjBL (Table 4) shows that there is large agreement of managers overseas with managers at home. The three competencies developed strongest by PjBL as perceived by managers overseas are also the three competencies developed strongest by PjBL as perceived by managers at home (Table 4, highlighted green), namely, "Creative, innovative and pro-active…", "Effective team membership…" and "In depth understanding…". The situation is similar for the three competencies that are perceived to be developed least by PjBL (Table 4, highlighted orange). Managers overseas agree with managers at home that "Application of systematic design…", "Conceptual understanding of mathematics…" and "Theory based understanding…" are developed least by PjBL. These findings seem to indicate that managers overseas and managers at home have a similar perception of the contribution of PjBL to developing engineering competencies. Furthermore, it seems to show that the sector and size of respondents' companies does not have a big impact on engineers' perceptions on engineering skills. However, the remaining research questions and the related results allow for a more differentiated discussion.

The second research question is concerned with the perceived contribution of traditional learning to the development of engineering competencies as perceived by managers overseas and managers at home. Although this is not the primary concern of this study, answering this question allows an important comparison with the findings related to question one. The results as shown in Table 5 show much less agreement between the managers overseas and the managers at home than the previous results related to the contribution of PjBL. The three highest ranking competency elements as perceived by managers overseas (Table 5, highlighted green) are not among the three highest ranking competencies as perceived by managers at home. Furthermore, of the three lowest ranked competencies as perceived by the managers overseas (Table 5, highlighted orange), only two are lowest ranked by managers at home. "Theory based understanding…" is ranked 15 by managers overseas, whereas it is ranked second by managers at home. Since the managers considered here received comparable engineering training in China, this might indicate that the theory-based understanding is insufficient for overseas assignments, whereas it is sufficient for assignments at home. Since neither PjBL, nor traditional learning, contribute much to the development of theory based understanding as needed on overseas assignments, HEIs should investigate this further in order to identify improvements. As shown in the previous paragraph, managers agreed on the low contribution of PjBL on developing theory based understanding, and it serves as an important reminder for HEIs that PjBL needs to include sufficiently the theoretical basis of project tasks in order to avoid neglecting the underlying theory.

The third research question looked at the difference between contribution of PjBL and contribution of traditional learning as perceived by managers overseas and at home. Managers overseas perceive a significant difference only regarding two competency elements (Table 6, highlighted blue), namely, "In depth understanding…" and "Creative, innovative and pro-active…". Not surprisingly, they see both competency elements better developed by PjBL than by traditional learning. This is very different from the perception of managers at home, who see all competency elements significantly better developed by PjBL than by traditional learning (Table 7, highlighted blue) except two elements, namely, "Theory based understanding…" and "Conceptual understanding of mathematics…". Their perception regarding "Theory based understanding…" is in agreement with results of an earlier study, which found that Arab managers of engineers at home do also not see a significant difference between the contribution of PjBL and traditional learning regarding "Theory based understanding…" (Jaeger *et al.,* 2018). Regarding the study here, the different perceptions of managers at home when comparing with managers overseas might be related to the fact that managers overseas are more reluctant to hire fresh graduates and, therefore, did not experience positive results of the recent implementations of PjBL within the Chinese HEI's. Engineering education in China focussed in the past much on theoretical foundations (Li and Guo, 2007), whereas there is a stronger emphasis on PjBL more recently (Zhang *et al.*, 2014). This perception of managers at home proves the effectiveness of PjBL in developing competency elements, and there is a strong support for initiatives to implement PjBL within engineering programs in China and beyond.

The fourth research question is concerned with the difference between managers overseas and managers at home regarding their perceived contribution of PjBL (Table 8). Confirming the previous interpretation, managers at home have a higher opinion of PjBL than managers overseas. They perceive a significantly higher contribution by PjBL regarding all competency elements -- except "Theory based understanding…" and "Conceptual understanding of mathematics…" (Table 8, highlighted blue).

The fifth research question covers the significance of differences (Table 9, highlighted blue) regarding perceptions of managers overseas and managers at home concerning traditional learning of the considered competency elements. The coherency of project execution at home may lead to the perception that current knowledge can be discerned quite well by traditional learning. Contrary, managers overseas may realize more the impact of diverse stakeholders and different project approaches and frameworks, which leads to the perception that traditional learning is limited in its contribution to the "Discernment of current knowledge…". This finding may encourage HEIs to include students of diverse backgrounds and experiences in PjBL projects in order to prepare better for overseas assignments.

The perceived lower contribution of traditional learning to the development of "Application of established engineering methods…" at home (Table 9) can be interpreted in a similar manner. Because of the diverse project context overseas, including engineering methods that are not considered "established methods", managers overseas might perceive a higher contribution of traditional learning in developing the "Application of established engineering methods…". However, considering the interpretation of the previous paragraph, this perception needs to be taken with caution since managers overseas seem to have less experience with graduates who experienced PjBL than their counterparts at home. In any case, the finding reminds HEI's to ensure sufficient learning facilitation when students apply established engineering methods within PjBL contexts.

The perceived higher contribution of traditional learning to develop "application of systematic design…" (Table 9) at home confirms the previous interpretation. Managers overseas are exposed to varying design standards during different projects (Li and Furusaka, 2012), and they expect engineers being able to familiarize themselves with new design standards. Therefore, they perceive a lower contribution of traditional learning to develop this competency compared to managers at home, who might work continuously with the same standards and expect HEIs to prepare engineering students accordingly. This means for HEIs, that they should aim more at engineers' ability to use different standards rather than focusing exclusively on the standards used at home, in order to better prepare for an overseas context. The following conclusions can be drawn from this study.

5 Conclusion

In order to identify the perceptions of Chinese Engineering managers at home (i.e. in China) and overseas (i.e. in the GCC region) on PjBL and traditional learning, questionnaire based interviews were carried out. The findings show a general agreement between the two groups regarding the contribution of PjBL, but they also show that PjBL needs to sufficiently include the theoretical basis of project tasks. Managers at home see 14 competency elements better developed by PjBL than by traditional learning (i.e. all *engineering application ability*, all *professional and personal attributes*, and four of the six *knowledge and skills* competency elements), whereas managers overseas only see 2 competency elements better developed by PjBL than by traditional learning (i.e. one *knowledge and skill* and one *professional and personal attributes* competency element). The perception of managers at home proves the effectiveness of PjBL in developing competency elements, and it is a strong support for initiatives to implement PjBL within engineering programs in China and beyond. Furthermore, HEIs are encouraged to include students of diverse backgrounds and experiences in PjBL projects in order to develop their discernment of current knowledge. The finding regarding "Application of established engineering methods…" reminds HEI's to ensure sufficient learning facilitation when students apply established engineering methods within PjBL contexts. Finally, in order to prepare engineering students better for an overseas work context, HEIs should aim more at, first, the ability to use alternative design standards and codes than focussing exclusively on the design standard used at home.

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PBL Framework for African Higher Education: A Case Study In UENR

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Abstract

The traditional teaching and learning methods pose several challenges in Higher Education in Ghana and Africa at large. Some of the challenges are related to low creativity and poor problem-solving ability due to the use of the traditional pedagogical approach. Since the introduction of Problem Based Learning in 1960 at McMaster University in Canada many educational reforms have been achieved by aiding students to work through the diverse and complex problems that arise in the industry by developing their problem-solving ability and creativity. PBL is widely regarded in the developed countries as a successful and innovative tool for training students to be problem-solvers at the end of their study. We propose a PBL framework for training graduates to help produce the right manpower for the country. This study considers the behavior of both lecturers and students in UENR and the Infrastructure for teaching and learning. The framework inculcates the essential characteristics of the Aalborg PBL model to achieve the intended purpose. The model shares some similarities with the Aalborg PBL model in the formation or organization of groups, assessment methods, and theoretical principles of problem analysis in engineering. The framework applies an enhanced method in the integration of knowledge and practice, collaboration, and group work; these are influenced by our upbringing, early childhood education history and traditional believes.

Keywords: Problem Based-Learning, Framework, Infrastructure, Knowledge, Pedagogical

Type of Contribution: PBL Research

1 Introduction

Recent advances in the area of physical and applied sciences job market require confident persons that can comprehend the needs of the institution. Graduates who are capable of processing issues to understand a problem and applying their knowledge to solve the problem or real-world problems effectively are required nowadays in most firms. One new method that equips students to be self-confident and use the knowledge gained to solve real-world problems is PBL (Wee, 2004 & Jonasseh et. al, 2006).

In 1960 the PBL model was introduced by McMaster University, several other PBL models have emerged to improve the standard of learning in our institutions. Most of the PBL models are just an improvement of the 1960 McMaster University some of which including Australia (Yadav et. Al, 2011), Denmark (Barrows & Tamblyn, 1980), Iran (Dehkordi & Heydarnejad, 2008) and Singapore (Wee, 2004). Problem-Based Learning (PBL) model is self-learning concepts that follow constructivist and a collaborative learning theoretical principle that shares the same operational structures as Student-Centered Learning (SCL) method.

PBL is a very challenging learning approach that builds students in several areas like developing a team spirit in working together towards understanding a problem and sharing ideas to possibly solving the problem

(DeGoeli, 1997). This method aid students to acquire concepts and principles from each other through solving a real-world problem. Real-world problems bring the students into contact with the environment helping them translate the theoretical concepts and principles into operation to first analyze the problem and proceed to solve it. In solving the problem, the concepts and principles when putting into implementation become procedural knowledge.

Several works conducted by research on learning methods have pointed out that PBL is a good tool in achieving deep-content learning which is an intended learning outcome (Hmelo-Silver, 2004). Evidence provided in the literature suggests that students who engage in deep-content enhance their understanding of the course and it improves their performance in the future conceptualization of advanced problems. To make students acquire deep-content learning in a course then the problem to be solved should be properly structured to push students to achieve deep-content knowledge. A deep-content knowledge broadens the student's thinking ability in the use of in-depth concepts, principles, and procedures (Gijbels et. al, 2005). The conventional face-to-face equally has advantages but certainly not in terms of reaching the highest level of the bloom's taxonomy in application and synthesis. Several studies have shown the massive achievement of the conventional face-to-face learning method in the acquisition of concepts and principal knowledge (Gijbels et. Al, 2005 & Hung, 2006).

In a wider context, it is believed that PBL demonstrates a more effective knowledge of application or procedure than conventional learning approaches. In (Norman & Schmidt, 2000 & Dehkordi & Heydarejad, 2008) study was conducted with two separate groups. The first group was taught using the conventional teaching approach while the PBL learning method was applied to the second group. During the assessment of the two groups, group two demonstrated higher cognitive levels of application and evaluation while group one established knowledge in lower cognitive levels.

In this study, we propose a PBL framework for training creative and problem-solving graduates to help produce the right manpower to engineer a real-world solution in the country. This framework considers the behavior of both staff and students in UENR and Infrastructure for teaching and learning. The framework adopts the essential characteristics of the Aalborg PBL model to achieve the intended purpose. The model shares some similarities with the Aalborg PBL model in the formation or organization of groups, assessment methods, and theoretical principles of problem analysis in engineering. The proposal applies an enhanced method in the integration of knowledge and practice, collaboration, and group work; these are influenced by our upbringing, early childhood education history and traditional believes.

2 Proposed PBLFramework

Studies conducted by (Segalas et. al, 2009) concluded that PBL achieves better learning outcomes from a field of study through active participatory work through groups and group community projects. We noted from literature and our experience from teaching for several years that group work and presentation is not an automatic basis for all-inclusive learning. However, in PBL, the problem to be solved is presented and students are organized in smaller groups to work hand-in-hand to solve the problem. The students are required to engage with each other to come out with opinions, ideas, and ways to develop solutions and alternatives solutions to the problem. Students evaluate and analyze the problem before them depending on the different social contexts and setting mostly derived by where and how they relate the problem to society. The student is allowed to share their personal experiences and link it with the problem at hand to help conceptualize ideas to formulate solutions in a collaborative learning environment.

The PBL concepts allow students to relate with most things like the environment, objects, and people's concern to have the first-hand experience and help them make sense out of the problem posed by the facilitator. At each stage, feedback is collected through several means, for example through ideas and contributions from stakeholders or the facilitator to drive their path towards coming out with an innovative solution or prototype. The feedback receives is to aid the group to:

1) decide collectively to change their direction towards the solution to the problem
2) decide to change the direction in the conceptualization and understanding of the problem
3) decide to proceed but rather change their responses towards the building their solution.

Following the study from (DeGoeji, 1997), PBL consist of; the problem to be solved, organizing the students into smaller groups, the facilitator, developed learning objectives that will be centered around a goal-oriented study, self -directed time for learning by groups, mapping of concepts and evaluation by groups. In the traditional face-to-face learning approach students are on the receiving side whiles the tutor/teacher delivers concepts from the beginning of the teaching process to the end mostly with little or no involvement of the students, this usually takes place in a typical classroom. With the traditional face-to-face learning, approach teaching takes place in an ordered procedure mostly believed to be on an incremental basis, from basic/introductory gradually to the intermediate concepts/theories through to advanced principles of the course of study. The pedagogical approach of the face-to-face learning method is believed to be the best in terms of the development of the mental faculty of students. Whilst in PBL the problem is presented to the students before they learn the basic knowledge of the course. In this way, as the problem unfolds in progressive stages students are simulated to seek advanced knowledge in various forms in their efforts to evaluate and solve the problem. The main aim of this approach is to help students build the knowledge within a collaborative group-centered environment and supported by a facilitator’s direction.

2.1 Process of the PBL framework

The first stage is achieved by developing a set of good, well explained, and clear learning outcomes. The development is done by the facilitators with the help of the curricula. The assessment module is inherited completely from the Aalborg PBL module with little modification to fit our environment. The learning outcomes gives a clear and elaborate definition of problem definition boundaries. The pivot of the learning process rests on the wigs of the problem definition, hence the proposed PBL module puts a lot in to make sure the problem defined covers the entire scope of the developed learning outcomes.

The Aalborg problem definition module is incorporated with some support from the local industries of interest, to fine-tune the problem into real-world problems that our country is faced with presently and in the nearby future.Groups are formed after the problem definition stage. The group formation is well-explained in section 3.3. The course facilitator or facilitators divide the class into groups, sometimes using prior knowledge of the class history or previous group history as a guide. After the first three stages, students are introduced to PBL. Students are first introduced to PBL by the PBL center in a preparatory course. The facilitators also take time to explain the application of the PBL teaching and learning method to students. This broadens students' knowledge of the concepts of PBL and how it can be implemented in the course to achieve the learning outcomes of the course. A detailed explanation of this stage is below in section 3.4. The next stage is that the groups formed in stage 3 set into work and become research groups. The groups work with support from industries concerned, the facilitator, and some major stakeholders like the head of industries facing the problem at stake and lecturers handling similar courses.

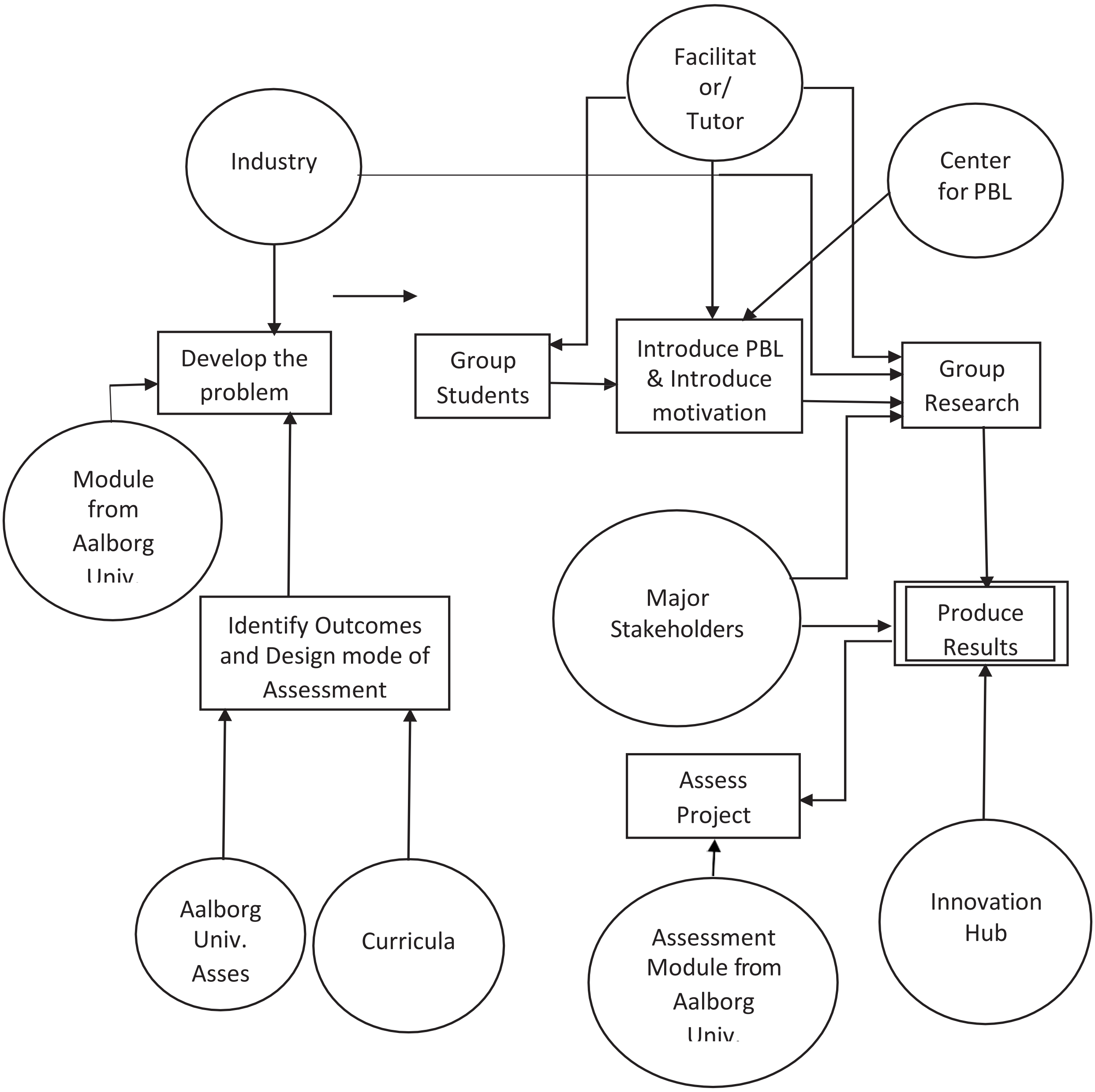

Figure 1: Proposed PBL Framework for Higher Educational Learning in UENR

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From this narrative, it is very clear that if care is not taken in the grouping and such a student from a very traditional Africa home with these traits is put in a group with people who are extroverts this student will never contribute to the group and will not raise any concern even if the group is on the wrong track and he/she knows. Adding to African tradition is our educational history. Our early-childhood development schools are mostly filled with teachers who have no proper training in education, these teachers are a serious contributing factor to some kids being very reserved and timid. Some kids are very innovative, out-spoken, and instrumental types who always want to do things by themselves in their early development stages. When they try to do things on their own and they are forcefully stopped on several occasions or speak out and the teacher shuts them up and even in some situations rain them with negative and demoralizing statements on some occasions will make the kid turn to be quiet and dull. This affects the kid's development and can transform him/her to be timid in life. Early Childhood development stages need special care and hence needs professionals with skills to handle such stages.

The religious background and beliefs of people in Africa are some time needs some critical consideration. The group must be properly constituted to aid harmony. Some Religions taboo certain foods and attitudes, and members of the group must respect the religious beliefs of others to create a conducive environment for collaborative learning.

Age is very important in Africa, so when forming a group, a blend of the ages will be very useful in achieving the objective of the PBL method. When the grouping is done properly and well little facilitation is needed to direct students to the construction and reconstruction of knowledge for real-life problem-solving (Baker, 2000a & Baker, 2000b).

3.4 Introduce PBL and Motivate the Students

This stage introduces students to the modern learning approach adopted by most developed parts of the world today. The local task force in UENR on the Erasmus + project titled "Enhancing Entrepreneurship, Innovation, and Sustainability in Higher Education in Africa" (EEISHEA) have been trained on the implementation of PBL in higher education. Based on the proposal of the EEISHEA, the University is putting plans in place to establish a PBL center to train students on how PBL works and the role of the student.

This research proposes to explain PBL with "learning by doing", where we start with a very simple example to make students understand the basic concept of the learning method. With our upbringing in Africa and early childhood education through to the tertiary, students get so used to the conventional face-to-face teaching and learning methods hence a smooth transition is necessary to make students cope. The straightforward task for students to present to different actors in new learning environments could cause frustration and kill the interest of students (Gijbels et. Al 2005). After the center trains the students, the course facilitator also takes students through the concepts of the PBL and how it can be implemented in the course to achieve the learning outcomes of the course. This is meant to educate the student on the knowledge he/she is supposed to acquire or gain by the end of the course and efficient ways to acquire the needed knowledge.

A pretest was conducted with "Level 200" Computer Science Students in a course titled "COMP 205: Systems Analysis and Design", the outcome of the training was very impressive.

3.5 Conducting Group Research

The organized groups start with a brainstorming session when groups define the problem with the help of the facilitator and major stakeholders and try to explain what they understand about the problem (background knowledge), what additional knowledge they need to learn more about (topics to research), and how they look for data (databases, interviews, etc.) (Onyon, 2012).

The groups are expected to meet and share ideas to write the problem as a statement and in some cases research questions. When they are stack, they result in asking the facilitator in some instances whereas in other instances they fall on to the main stakeholders from the industry for help. This activity carried out by the group is to come out with good research questions to aid in their work/project, without a good problem statement/research question the research process can be unguided.

To achieve the needed result within a record time, students are required to divide the project into several tasks and decide upon group roles and assign responsibility for researching topics necessary for them to fully understand the problem at hand. An initial hypothesis is developed to "test" the solution. This process continues until they are done with the final product.

3.6 Produce Results

After collective research, the group fashion products and presentations that put together their research, solutions, and learning. The style of the final/summative assessment is completely decided by the students. This step is treated as a research fair for groups to showcase their research and products. Students gather resources to advance contextual facts that inform their understanding, and then they collaboratively present their findings, including all alternative viable solutions, as research posters to the class, facilitator, and major stakeholders for assessment.

3.7 Assessment Methods and Implementation

The facilitator in this PBL is to direct the students thinking and reasoning faculty by actively posing questions and suggestions that will aid students to think out of the box and search for additional knowledge to better understand the problem at hand at each stage of the problem-solving process. During these interactions with the students, the facilitator monitors and evaluates group and individual progress. Each group is evaluated based on the context of the problem discussion meeting. At each stage of the group's work, evaluation takes place by the facilitator with the help of some major stakeholders in situations where the problem is taking from an industry (Gijbels et.al, 2005 & Urden, 2004).

In PBL students acquire much more knowledge and understanding of the course than the course content. The learning process includes the following; how to work with others, how to solve problems in a group, how to present their ideas clearly to an audience, and how to learn from their own mistakes. The assessment should capture some salient points like *what* they learned and *how* they came to learn it (Albanese & Mitchell, 1993).
The areas that our proposal emphasis in the assessment include content mastery, collaboration/participation, and presentation style, meeting deadlines, and some elements specifics depending on the project and course of study.
For this assessment method to be more efficient lecturers and students should be motivated to play their roles more efficiently.

Students should be motivated by taking them to the industry or industries to interact with the environment and the people/workers to have a first-hand experience of the problem.

The promotion criteria in UENR and Ghanaian institutions consider only the following; Promotion of Knowledge, Community Service, and Teaching. Lecturers should be motivated to adopt this new method to train our students to be citizens who can act in unknown contexts and adapt to a changing environment. Hence to encourage lecturers to change from the conventional face - to-face teaching methods to fully embrace the PBL method. Some kind of motivation should be given to the lecturer to encourage them to stick to this teaching and learning method.

The only way to sustain the use of PBL is motivation from both the angle of the lecturer and the student. Figure 1 presents the framework of the PBL learning method proposed for UENR.

4 Stages of Knowledge Acquisition and Development Using PBL Model

Figure 2 below illustrates the process of educational development stages that students pass through when trained using the proposed PBL model. The framework developed encourages facilitators to design a real-world well-structured problem. Group researching makes students share ideas and gain a better understanding of the problem and subject understanding. Students equally develop metacognitive knowledge and a good understanding of scientific principles and concepts. Team working skills is an important component required in every workplace during the process each student in the group develops this teamwork skills as well as build some good personal qualities necessary for life.

Higher cognitive knowledge of the application is gained by a combination of a good understanding of scientific principles and concepts, meta-cognitive skills, and a deep sense of problem understanding and evaluation. Teamwork skills coupled with personal skills and a higher cognitive knowledge of applications prepares students for employment and life.

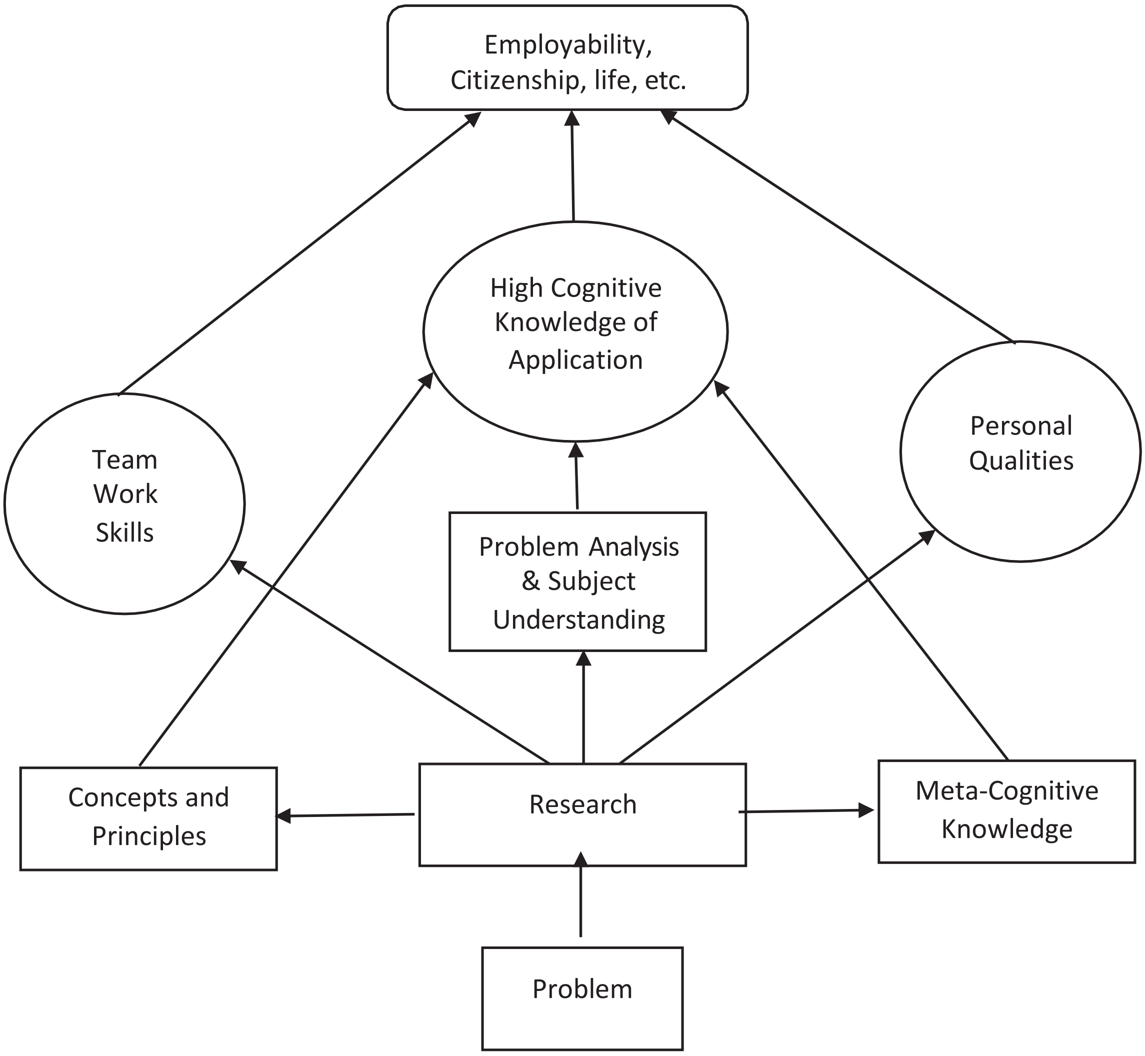

Figure 2: Knowledge and Skills Acquisition Model Using the PBL Learning Method

5 Conclusion

Based on the African setting and our educational background it will be very challenging to implement the PBL modes as it appears in most parts of the world like Denmark, Australia, and Canada. Some adjustments will be very beneficial for the successful implementation and sustainability of the PBL module.

Africa is one of the biggest continents and endowed with natural resources that need the right manpower with the requisite knowledge in the industries to help solve real-world problems that they encountered daily. The conventional learning approaches turn out students with a lower cognitive level ofknowledge.

An enhanced PBL framework is proposed that will help train graduates to be creative and problem-solving to augment manpower deficit in the country. This framework takes into consideration the means to harness the behavior of both staff and students in running an efficient learning system. The framework adopts the essential characteristics of the Aalborg PBL model with some modifications to aid it to achieve the intended purpose.

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Characteristics, benefits, challenges, and socio-cultural factors of implementing PBL in Qatar

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Abstract

While project- and/or problem-based learning has been implemented in higher education worldwide for several decades, both modes of PBL remain a new phenomenon in Qatar. Over the past few years, several research projects have been conducted examining the initial PBL implementation experiences and effects in Qatar. In order to provide an overall picture of implementing PBL in Qatari educational institutions, the current study provides a review of literature on how PBL has been practiced, what benefits have been perceived and documented, what challenges have been encountered, and what the future prospects are of PBL. The following research questions served as a guide for this study: What are the characteristics of PBL implementation in Qatar? What are the benefits and challenges of implementing PBL in Qatar? What socio-cultural factors have contributed to or constrained PBL implementation? Fifteen articles were selected that were appropriate for the literature analysis. The findings that emerged from the synthesis of the 15 papers included three overarching themes: preparation for change, implementation of change, and evaluation of change. Within each theme, both teachers' and students' perspectives were summarized. From the perspective of students, subthemes were identified including approaches to learning, views on and characteristics of collaboration, student engagement, and agency. From the perspective of teachers, the subthemes identified were readiness for change, fidelity of PBL implementation, agency development, and professional identity negotiation. In addition, socio-cultural factors contributing to and constraining the implementation of PBL were also identified and discussed. The paper concludes with recommendations on the prospects of implementing PBL in the educational system of Qatar and beyond.

Keywords: Implementing PBL, Qatar, benefits, challenges, socio-cultural factors

Type of contribution: PBL review

1 Introduction

Over the decades, PBL (project- and/or problem-based learning) has been implemented at diverse educational levels worldwide as a student-centered approach aimed at providing students with 21st century skills and professional competencies (Savin-Baden, 2014). Literature in the field has provided various ways to define the term PBL. For example, Savery defined problem-based learning as “an instructional learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem” (2015). In their systematic review of project-based learning, Helle, Tynjälä, & Olkinuora (2006) highlighted the role of a project in providing solutions to identified problems according to a set of objectives, a timeline, end products such as reports and designs, and teamwork. Further, the Aalborg PBL model has emphasized a combination of problem, project and teamwork as an ideal way of implementing PBL with numerous evidences provided over the decades (Edström & Kolmos, 2014).

Despite increased global attention, PBL remains a new phenomenon in the Middle Eastern context in general, aside from its adoption by a few medical schools and one engineering school, the Australian College of Kuwait. In the State of Qatar, the Qatar National Vision 2030 (General Secretariat for Development Planning, 2008) states that the country’s economy is to move from one dependent on oil and gas to one based on the creation, distribution and use of information, emphasizing the importance of scientific knowledge and development. As a part of this national strategy, all educational institutions in Qatar have been designated as the starting point where creativity and innovation in teaching and learning should be implemented in order to help students develop 21st century skills (Du & Chaaban, 2020). To achieve this goal, in 2017 the Ministry of Education and Higher Education (MOEHE) of Qatar pledged a nationwide initiative introducing project-based learning into the curriculum of several subject areas including science, mathematics, English as a foreign language (EFL), and Arabic in all governmental primary schools. In post-secondary education, Qatar University (QU), the country’s foremost institution for higher education, has been leading educational innovation in the country by encouraging diverse teaching and learning initiatives that address student-centered learning and instill professional competencies in their graduates. In addition, one newly-established medical school adopted a problem-learning curriculum upon inauguration in 2016. Likewise, since 2018 the College of Engineering has encouraged instructors to implement project-based learning within the current scope of courses. In addition, several colleges (e.g. College of Business, College of Education) are implementing PBL within the current scope of courses.

Over the past years, several research projects were conducted examining the initial PBL implementation experiences in Qatar. In order to support a longer-term implementation of PBL (either problem or project-based learning, or both problem and project-based learning) at diverse educational levels in Qatar, there is a need to synthesize the current knowledge and practice. To meet this end, this study aims to provide a comprehensive picture of PBL implementation in Qatar, through an examination of literature to gain an overview on how PBL has been practiced, what benefits have been perceived and documented, what challenges have been encountered and what the future prospects are for PBL. In particular, the study is guided by the following research questions: What are the characteristics of PBL implementation in Qatar? What are the benefits and challenges of implementing PBL in Qatar? What socio-cultural factors have contributed to or constrained PBL implementation?

2 Methodology

To answer the research questions posed in this study, a systematic review method was employed methodologically to identity the diverse current PBL implementation practices in Qatar. Following the research questions, the research protocol and searching process were conducted following the suggestions of Borrego, Foster, and Froyd (2014). The following criteria were used for the selection of literature:

1) Selected research articles shall be published in English language in peer reviewed sources (journals, books and conference proceedings).
2) Selected research shall include empirical data related to PBL at diverse educational levels in a Qatari context.

3) In the reported studies, PBL shall be part of the schooling and curricula rather than a part of extracurricular activities.

The searching and filtering methods included a few procedures: first, a literature search was conducted in the data bases of ERIC, EBSCO, SCOPUS, and GOOGLE with keywords of "PBL," "problem-based learning," "project-based learning," or "problem-orientation" and "Qatar." A total of 30 publications (including four master's degree theses) was found at an initial stage. Screening by titles, keywords, abstracts, and full texts excluded 13 articles. Reasons for exclusion were that the papers mainly described PBL as a theoretical ideology for Qatari education, PBL as an idea for organizing a course without empirical data, or PBL was recommended in the papers but the data had no relation to PBL or Qatari context. After the screening process, 17 articles remained which fulfilled all three criteria, including 11 journal articles, 2 conference papers and 4 master's degree theses. Data from two of the master's theses had been included in two of the published articles, so a total of 15 studies were counted in the analysis.

Analysis process include the following procedures:

1) Initial themes were suggested according to the research questions.
2) Under each theme, subthemes were developed through a bottom-up approach to coding, identifying categories and summarization.
3) Initial themes and subthemes were integrated to constitute the final findings combining individual analysis and collective discussion.

3 Findings

3.1 What are the characteristics of PBL implementation in Qatar?

Table 1, in Appendix 1, provides an overview of the 15 studies that fit the review criteria in this study and includes article titles, publication sources, educational level, types of PBL implementations, aims of the study, and empirical data sources. To follow the structure of a recent literature review on PBL in engineering (Chen, Kolmos, & Du, 2020), we also categorized these 15 studies based on the ways problems and projects are defined and practiced, and the way teamwork and assessment methods were justified in the givencontext.

3.1.1 Implementation by levels of education

The scope of the identified studies included primary education (N = 6) and post-secondary education (N = 9). The subjects of these studies included English, math, and science for primary schools, and engineering, medicine, pharmacy, and English in the college foundation program. Participants of the studies mainly include students and teachers. One paper also addressed perspectives of school leaders and professional development developers (Du & Chaaban, 2020).

All eight of the studies of post-secondary education were conducted by researchers from Qatar University. Among them, seven studies drew empirical data from students and instructors from the same university, one addressed problem-based learning in an undergraduate final-year pharmacy course (Nasr & Wilby, 2017), three reported problem-based learning in curriculum at an early stage undergraduate medical program (Du, *et al*, 2016; Du, *et al*., 2019; Kassab, *et al*., 2019), and three documented the effect of problem and project-based learning implemented in four civil engineering courses (Du, *et al*., 2018; Du, *et al*., 2019; Du, *et al*., 2020; Naji, Ebead, Al-Ali, & Du, 2020). In addition, one master's thesis was conducted by a student from Qatar University with data collected at a community college in Qatar (Mabrouk, 2018). In addition to these eight studies, one study was conducted by computer engineering researchers from Qatar University (Miao, Samaka, & Impagliazzo, 2013). In that study, the authors (in collaboration with researchers from Germany) developed an online technology-supported project-based learning program to be used in primary education and reported feedback from schoolteachers. Although the authors published several conference papers on the development of this application to be potentially used in a PBL environment, we could not find any published studies on the further implementation of this PBL program. We categorized this study as primary education because participants were schoolteachers for the test of this application. In addition to this article, five articles reported that problem or project-based learning were implemented in different subjects in lower secondary education: One reported students' attitude change towards science learning through a problem and project-based learning in preparatory classroom (Grade 9) (Faris, 2008), one reported a longitudinal study on teachers' change of beliefs and practices through implementing problem-based learning in the math classroom (Al Said *et al*, 2019), and three addressed project-based learning in English as a foreign language by exploring teachers' perception of school support for PBL (Alkhatabeh, 2018), teachers' readiness to change (Du, Chaaban & AlMabrd, 2019), and their implementation process (Du & Chaaban, 2020).

3.1.2 Implementation by levels/types

In their review work, Chen, Kolmos, and Du (2020) identified four levels or types of PBL implementation in engineering education based on 108 articles written between 2000 and 2019: course, cross-course, curriculum, and project (co-curricular). At the course (e.g. an engineering course) or subject level (e.g. mathematics as a subject in lower secondary education), PBL is used to organize the teaching and learning activities and lectures in order to reach the course or subject objectives within the scope of the given course or subject with a duration of one semester. Cross-courses type of PBL implementation usually enhances multidisciplinary knowledge and skill development involving students from different disciplinary backgrounds working together. At the curriculum level, PBL serves as the core of a curriculum which aims to support the development of the overall program objectives, such as 21st century skills and professional competencies. In this way, PBL serves as the main teaching and learning activity with the assistance of lectures, field work, and other sources of learning. Although the duration of each PBL cycle at this level may vary, PBL remains the core of the entire four to five-year study program. Project type of PBL implementation often refers to those extracurricular activities where students join structured activities in their spare time. In the current study reviewing published practices in Qatar, two types of PBL implementation are identified: course/subject and curriculum. Aside from the three studies that were at a curriculum level in the College of Medicine at Qatar University, the majority of the studies were conducted within the scope of a course or a subject classroom (e.g. math, science, and English as a foreign language in lower secondary education, and pharmacy, engineering, and English as a foreign language in post-secondary education).

3.1.3 Data sources for the current studies

The identified studies drew on empirical data from multiple methods. Among the articles on primary education, two articles used qualitative data generation methods such as interviews and classroom observation (Du, Chaaban & AlMabrd, 2019, Du & Chaaban, 2020). Two other articles used quantitative studies through self-reported questionnaire surveys (Alkhatabeh, 2018; Faris, 2008; Miao, Samaka, & Impagliazzo, 2013). One article presented a study that used metaphor method (Al Said, *et al*., 2019), lesson plan analysis and interviews identifying primary math teachers' change or lack of change in their beliefs and practices after having implemented problemed-based learning for three years. Among the post-secondary articles on PBL in the medical curriculum, one article included a study based on both qualitative and quantitative analysis of a Delphi study identifying experts' and instructors' opinions on the essential professional competencies developed at an early stage of a problem-based learning medical curriculum. Two articles included quantitative studies relying on statistical analysis to measure students' development of the needed skills and competencies in a problem-based learning setting (Du *et al*., 2016; Kassab *et al*., 2019). Four articles documented student learning with a problem and project-based learning curricula implemented in four civil engineering courses. The first was mainly based on qualitative focus groups with 24 students (four project teams) (Du *et al*., 2018). The second was based on a mixed-method study of two questionnaire surveys given to 77 students and 17 focus groups of 88 students which explored the change of their approach to learning and views on collaboration in response to project-based learning (Du, *et al*., 2019). The third study

(Du, *et al*., 2020) used quantifying qualitative data methods to analyze focus groups and observations of 97 engineering students working in 17 project teams to identify patterns of developing self-directed learning strategies and collaboration within the team. The fourth article (Naji, Ebead, Al-Ali, & Du, 2020) explored forms of student engagement in PBL settings, quantifying qualitative data of observations and group interviews with 23 project teams (116 students) in four different PBL undergraduate civil engineering courses. In addition, the study on the pharmacy course (Nasr & Wilby, 2017) included feedback and evaluations of the PBL practices from two instructors.

3.1.4 PBL principles

Attention was also given to the PBL principles for analyzing literature, namely problem, project, teamwork, and assessment (Chen, Kolmos, & Du, 2020). Although the concept of "teamwork" has been used consistently as an important element of PBL in all the studies in Qatar, the concepts "problem" and "project" were used differently. In actuality, the concepts were only clearly defined in the studies of medical curriculum (problem-based learning) and the engineering courses (problem- and project-based learning). In particular, the pharmacy course (Nasr & Wilby, 2017) and medical curriculum used the concept of problem-based learning (Du *et al*., 2016, Du *et al*., 2019, Kassab *et al*., 2019), as did the primary math classroom (Al Said, *et al*., 2019). This study on math teachers' changing beliefs and practices when implementing problem-based learning (Al Said, *et al*., 2019) is embedded in a small scale teacher development project. This is different from the nation-wide MOEHE initiative on project-based learning by MOEHE, in which teachers at the lower secondary education level (K3-6) collaboratively identified topics and problems for projects to be conducted by students in teams (Alkhatabeh, 2018; Du, Chaaban & AlMabrd, 2019, Du & Chaaban, 2020). The study conducted in 2008 by Faris (2008) was mainly an individual initiative using both concepts of "project" and "problem" in a science classroom. In the studies of engineering courses, both "problem" and "project" are used in structuring the overall course design (Du *et al*., 2019, Du *et al*., 2020). In their designed engineering courses, Miao, Samaka, & Impagliazzo's study (2013) intended to include both "problem" and "project," although there was no application and implementation mentioned. While assessment has been mentioned as a challenge in studies about using project-based learning in primary education (Alkhatabeh, 2018; Du, Chaaban & AlMabrd, 2019, Du & Chaaban, 2020), only the articles on post-secondary education addressed the justification and design of new assessment methods to support achieving PBL goals (Du *et al*., 2019, Du *et al*., 2020, Kassab *et al*., 2019).

3.2 Benefits and challenges

Benefits of using PBL in the classroom were identified through the analysis of the reviewed studies. The majority of the studies reported that PBL benefited student learning regarding improved student interest, engagement, and motivation, development of application, problem solving and analysis skills, and sense of responsibility. In particular, Du *et al*., (2019) identified improvement of deep learning from the pre- and post-PBL class assessments. Improved collaborative learning views and skills have also been addressed in a few studies (Du *et al*., 2019, Du *et al*., 2020, Kassab *et al*., 2019; Naji, Ebead, Al-Ali, & Du, 2020).

Several challenges were identified in this review. First, at an individual level, both students and teachers faced challenges of insecurity due to lack of understanding and insufficient prior knowledge and experiences related to PBL, and both teachers and students reported students' lack of teamwork skills (Alkhatabeh, 2018; Al Said *et al*., 2019; Du, Chaaban & AlMabrd, 2019, Du & Chaaban, 2020; Du *et al*., 2016; Du *et al*., 2019, Du *et al*., 2020; Naji, Ebead, Al-Ali, & Du, 2020). Due to the feeling of insecurity and lack of PBL skills, students, despite an increase in self-directed learning, tended to rely on their teachers as the major source of "correct answers." Second, at a curriculum level, there remained a lack of alignment between the curriculum requirements and expected learning goals and outcomes from PBL. Teachers expressed concern about not being able to accomplish overall curriculum requirements, and how the assessment could be justified to fit the PBL goals (Alkhatabeh, 2018; Al Said *et al*., 2019; Du, Chaaban & AlMabrd, 2019, Du & Chaaban, 2020; Du *et al*., 2018; Naji, Ebead, Al-Ali, & Du, 2020). These concerns were particularly reflected in the studieson

PBL at a subject or course level. Finally, teachers reported a lack of institutional support regarding the provision of an appropriate time schedule and classrooms to facilitate PBL sessions (Alkhatabeh, 2018; Al Said *et al*., 2019; Du, Chaaban & AlMabrd, 2019, Du & Chaaban, 2020; Du *et al*., 2016; Du *et al*., 2019, Du *et al*., 2020; Naji, Ebead, Al-Ali, & Du, 2020).

4 Discussion and conclusion

This paper analyzes 15 published studies on PBL implementation in Qatar. The literature analysis illustrates two major levels of PBL implementation, course level and curriculum level, in Qatari lower-secondary and post-secondary education. At a course or subject level, current PBL practices are diverse and can be found in various subjects in lower-secondary education such as science, math, and English as a foreign language (EFL), and pharmacy, engineering, and EFL courses in post-secondary education. Among all of the studies reviewed, PBL was only implemented at a curriculum level in the College of Medicine at Qatar University because the medical school was established in 2016 and the PBL curriculum was implemented upon inauguration. The fact that the majority of the implementations are at a course or subject level suggests that it is a challenging task to implement change initiatives and transfer from teacher-centered lecture-based learning (LBL) to a student-centered PBL environment. Support is needed in the process of transition. Teachers and students need to be provided with the proper knowledge and skills to implement PBL. Before institutional and societal culture can be changed to support long-term implementation of PBL, further evidence of improvement and justification must be provided.

The review identified certain benefits of PBL perceived by students and teachers, which also supported the general results of PBL literature internationally (Chen, Kolmos, & Du, 2020). A few challenges were also reported. These challenges are embedded in the local culture and may be attributed to a few sociocultural factors related to the Arab context. Historically, teachers in Arabic culture play the role of master of knowledge, which explains why both teachers and students in a PBL setting still see the teacher as the major authorized source of knowledge and “the truth” (Du, *et al*., 2020; Naji, Ebead, Al-Ali, & Du, 2020; Sabah & Du, 2018). This is also related to teachers’ lack of prior experiences and lack of beliefs or skills needed to support student-centered learning (Sabah & Du, 2018). To support this shift in mindset, professional development activities focused on providing teachers with a learner-centered experience in order to change their pedagogical beliefs are essential (Du, *et al*., 2020; Miao, Samaka, & Impagliazzo, 2013; Sabah & Du, 2018).

In regards to the current overview of PBL implementation in Qatar, a few points can also be made relating to the history and culture of education. First of all, in the realm of education in Qatar and many other Arab states, authority is not to be challenged. Authority should be believed to be delivering the best advice in the interest of service to the population. In practice, this means that in Arab culture, a teacher is seen as a “messenger” of information, a major authorized source of knowledge (Du, Chaaban, Sabah, Al-Thani, & Wang, 2020), and a manifestation of this centralized system. On the other hand, the Islamic view conveyed through Quranic verses encourages knowledge seekers to question and to contemplate. Second, the Qatari cultural mindset might create an interesting challenge to PBL. Despite Qatar’s many reforms toward decentralization, the country still operates in a centralized way. As a matter of fact, the Education for a New Era recommended creating a decentralized system to improve education in Qatar (Brewer *et al*., 2007). This decentralized system would endow schools and teachers with more authority to create a new education experience. This reform did not bear fruit and the system bounced back to a “chocking” centralized system. Furthermore, because the government currently expects the development of student-centered learning with the purpose of fostering 21st century skills in students, PBL can serve as the catalyst of change to encourage the Islamic principle of “Tafakur and Tadabur,” that is, to think critically. Enlightenment was reached inherently in Islamic civilization when these concepts were at the heart of knowledge seeking with reflection. Nevertheless, in the past lecture-based teaching has been the prevailing pedagogical practice which stagnates knowledge seeking.

A few recommendations may be made based on the results of this study. First, although PBL has been practiced at a beginning level in Qatar, the implementation was mainly piloted in lower secondary and post-secondary education. This indicates a gap in the educational pipeline with regard to developing skills and competencies developed from PBL. In post-secondary education, PBL was only implemented in English as a foreign language, engineering, and medical programs. This suggests that PBL should be further developed in secondary and post-secondary institutions, leading to expanding the benefits of PBL across more grade levels as well as addressing the challenges of implementing PBL. Second, future implementation of PBL should be presented to teachers and students with a clearly defined concept and instructional model before the actual implementation. Third, few of the current studies reported the effect of PBL on student learning, which suggests more research needs to be conducted to document its effect. Fourth, the literature analysis also indicates that more mixed-method research should be carried out in the future to identify the overall effect and results of PBL, to provide insights on the issues and coping strategies needed for PBL, and to address sociocultural factors in the adoption of PBL.

This review has a few limitations. First, the paper only reviewed published studies in the context of Qatar. The results are provisional to a Qatari context, although it would be interesting to compare the identified implementation characteristics with other countries in future studies. Second, the selection of articles mainly followed the three criteria listed in this study. This may have excluded other studies that have been published in Arabic language or in other sources. There may be practices of PBL in other educational institutions in Qatar that are not included due to the selection criteria in this study.

To conclude, regardless of the form of implementation, PBL can be regarded as a promising pedagogical approach in response to the Qatar National Vision 2030 goal of producing students and graduates with 21st century skills ready to create an innovative and entrepreneurial environment geared toward sustainable development. For this purpose, results of this study suggest that more research efforts are needed to better support a systemic educational change such as the implementation of PBL in the Qatari context, in particular with regards to overcoming cultural constraints.

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Appendix 1

Table 1: An overview of findings

No	Publication	Publication source	Education level	Implementation	Aims	Empirical data sources	Problem	Project	Team and class	Assessment methods
1	The Impact of PBL on the Students' Attitudes Towards Science Among Ninth Graders in Hamza Independent School	Online Submission (ERIC)	K9 Qatari governmental preparatory school	One class	To test if the use of PBL would improve the students' attitudes towards learning science among ninth graders in one school.	A questionnaire survey on attitude with 22 (out of 25) students in the class	Teacher defines the problem	Two one-month-long projects	25 students no team information	Formative and summative
2	Facilitating Teachers in Developing Online PBL Courses. (Miao, Samaka, & Impagliazzo, 2013)	*IEEE on Teaching, Assessment and Learning for Engineering (TALE)*	An online PBL application developed by Computer Science Faculty (Qatar University)	School teachers were invited to participate in a workshop for test the technology by teachers	To ascertain data surrounding the problem-based learning authoring and transformation environment (PLATE) project.	Survey with 35 teacher participants on their feedbacks of the application using a graphical PBL script editor or authoring tool of the PBL scripting language	NA	NA	NA	NA
3	*Introducing Problem-Based Learning into a Canadian-Accredited Middle Eastern Educational Setting. (Nasr & Wilby, 2017)*	*Currents in Pharmacy Teaching and Learning*	Undergraduate Pharmacy program at Qatar University	In a final year integrated case-based learning course	To describe the adaption and implementation of problem-based learning (PBL) within a pharmacy curriculum in a Middle Eastern context.	Evaluation of the PBL by 2 faculty Ss citation used without clearly defined methods and sources	Each case/ problem lasts 2-3 sessions. Ss receive a case in the 1st session and determine learning needs to solve the case and address the primary drug therapy problem.	No project	4 teams of 6 students each	In the last session the faculty reviewed the answers (4th day).
4	Preparing Foundation-Year Students for Medical Studies in a Problem-Based Learning Environment: Students' Perceptions. (Du *et al.*, 2016)	*Health Professions Education* (SCOPUS)	Undergraduate Medicine program at Qatar University	In a first year PBL sessions of the medical education program	To investigate how medical students in their first year perceive the progression of appropriate learning skills when studying in a PBL medical curriculum via the support of a course aiming at facilitating students with these skills.	A questionnaire survey with 50 out of the 59 (19 males and 31 females) students responded and self-evaluated a list of learning skills according to the course objectives pre and post the course.	Medical problems lasting 1-2 weeks from problem start to finish	No projects	8-10 students on each team	Various assessment including formative and summative methods, e.g. triple jump tests and individual student portfolios
5	*Identifying Essential Competencies for Medical Students. (Du et al., 2019)*	*Journal of Applied Research in Higher Education* (SCOPUS)	Undergraduate Medicine program at Qatar University	In the 2nd year PBL sessions of the medical education program	To identify essential profession-related competencies, clinical knowledge and skills that medical students should develop in the early stages of their education for future professional practice.	A Delphi study with two panels including 10 international, regional and national experts of medical education and 18 PBL facilitators	Medical problems lasting 1-2 weeks from problem start to finish	No projects	8-10 students on each team	Not mentioned

6	Measuring Medical Students' Professional Competencies in a Problem-Based Curriculum: a Reliability Study. (Kassab *et al.*, 2019)	*BMC Medical Education* (SCOPUS, SSCI)	Undergraduate Medicine program at Qatar University	In the 2nd year PBL sessions of the medical education program	To evaluate the reliability and validity of professional competency scores of medical students using the developed instrument in PBL tutorials.	Each group of seven to eight students in PBL tutorials (Year 2, n = 46) were assessed independently by two faculty members on four occasions. Reliability and validity were tested using G-theory.	Medical problems lasting 1-2 weeks from problem start to finish	No projects	8-10 students on each team	This study developed a new instrument to assess competences gained from PBL
7	Implementing PBL in Qatar-Civil Engineering Students' Views on their First Experiences from a Perspective of Constructive Alignment. (Du et al., 2018)	The 7th International Research Symposium on PBL proceeding	Undergraduate Civil Engineering courses	Course level	To explore engineering students' perceptions and views of learning and assessment at an initial stage of implementing PBL.	6 focus groups with 33 engineering students	Instructor proposes a theme and students identify concrete problems	A semester-long (4 month) project	4-6 people per team, 6 teams in total	Group grade based project report and presentation, which takes minimum 60% of the overall grade in addition to individual grade
8	Engineering Students' Approaches to Learning and Views on Collaboration: How Do Both Evolve in a PBL Environment and What Are Their Contributing and Constraining Factors? (Du *et al.*, 2019)	*EURASIA Journal of Mathematics, Science and Technology Education* (SCOPUS)	Undergraduate Civil Engineering courses	Course level	To investigate engineering students' approaches to learning and views on collaboration in the initial stage of changing to a PBL environment at the course level.	An explanatory mixed method with participants from four PBL-courses in Qatar and China including 197students respondence to two surveys, and 37 focus groups with 168 students	Same as above	Same as above	Same as above	Same as above
9	Engineering Students' Group-Based Strategy Use, Forms of Collaboration and Perceptions of Assessment in Team Projects – A Case Study in Qatar. (Du *et al.*, 2020)	*International Journal of Engineering Education* (SCOPUS)	Undergraduate Civil Engineering courses	Course level	To explore how engineering students' development of group learning strategies, forms of collaboration, and perceptions of alternative assessments. Also explore their interactions with peers and the correlations with student academic performance	A qualitative study with multiple sources of data including focus groups and observations of 91 engineering students in Qatar who worked on 17 project teams.	Same as above	Same as above	Same as above	Same as above
10	Comparing Models of Problem and Project-Based Learning (PBL) Courses and Student Engagement in Civil Engineering in Qatar	*EURASIA Journal of Mathematics, Science and Technology Education* (SCOPUS)	Undergraduate Civil Engineering courses	Course level	To explored forms of student engagement in PBL settings.	Quantifying qualitative data of data of observations and group interviews with 23 project teams (116 students) in four different PBL undergraduate civil engineering courses	Same as above	Same as above	Same as above	Same as above

11	*Math Teachers' Beliefs, Practices, and Belief Change in Implementing Problem Based Learning in Qatari Primary Governmental School (Al Said et al., 2019) (included data from the MA thesis by Al Said, 2018)*	*EURASIA Journal of Mathematics, Science and Technology Education (SCOPUS)*	Pilot study of problem-based learning in primary math classrooms in 4 governmental primary schools	Subject level	To explore math teachers' belief of their roles and perceptions of their belief change in implementing PBL in STEM K12 education.	A qualitative study with longitudinal data of interviews with 17 teachers, metaphor survey and lesson plan analysis	Teacher defines math problem	No project	Class size 30-40 Ss, each team 6-8 students	Results of problem solving is graded as the main math assessment method
12	Exploring the Concepts of Fidelity and Adaptation in the Implementation of Project Based Learning in the Elementary Classroom: Case Studies from Qatar. (Du, Chaaban, & ALMabrd, 2019) (included data from the MA thesis by ALMabrd, 2018)	*International Journal of Learning, Teaching and Educational Research* (SCOPUS)	A nationwide systemic level at all Qatari governmental primary schools – case studies at three schools	Subjects level – English as a foreign language	To explore teachers' first year experiences with PBL in a system-wide reform initiative in Qatari governmental primary schools	A qualitative study with longitudinal data of interviews with 11 teachers and classroom observations in the three case study schools	Teachers define topics or themes at the project starts	3 month duration with student presentation of results at the end of the project	Class size 30-40 Ss, each team 6-8 Ss	Project was not graded as part of overall assessment of student learning
13	Teachers' Readiness to Change to Project Based Learning in Qatari Government Schools (Du & Chaaban, 2020)	*Interdisciplinary Journal of Problem Based Learning.* (SCOPUS)	A nationwide systemic level at all Qatari governmental primary schools	Subject level 4 subjects – Arabic, English, Science and Math	To explore teachers' readiness to implement educational change such as PBL from the perspectives of the teachers, principals, and professional development (PD) facilitators.	Interviews with 21 participants including 11 teachers, 3 principals and 7 PD facilitators	Same as above	Same as above	Same as above	Same as above
14	School Support for PBL Implementations in EFL Primary Education. (Alkhatabeh, 2018)	Master's Thesis submitted to Qatar University	A nationwide systemic level at all Qatari governmental primary schools	English as a foreign language	To explore teachers' perspective on school support for PBL implementation.	Survey with 188 EFL primary teachers	Same as above	Same as above	Same as above	Same as above
15	University Students' Learning Strategies and Views on Collaboration in PBL – a Case Study in Qatar (Mabrouk, 2019)	Master's Thesis submitted to Qatar University	A community college foundation program	At a course level	To explore students' development of self-directed learning and views on collaboration in a PBL setting.	Interviews with 21 first year students (21 female and 6 male)	Ss chose from suggested topics by instructors	8 week-long	5-8 students	Not mentioned

Problem Based Learning at Kwame Nkrumah University of Science and Technology: Reporting on Policies, Practices and Needs

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Abstract

Problem-based learning (PBL) is well acknowledged to provide students with guided experience in learning, through solving complex real-world problems. In recent years, Ghanaian universities have been encouraged to adopt a new pedagogy that entrenches students' learning processes in real-life phenomena to prepare them for solving challenging problems in the field of work. In this paper, we agree that this can be realized by introducing PBL or PBL-like pedagogies into the Ghanaian higher education curriculum. For the first time, the present study investigates the available PBL policies and strategies, awareness of PBL or PBL-like practices and needs concerning PBL in a Ghanaian university. Data for the study were extracted from the KNUST-based BSU survey, with participants being educational managers, teachers, and students. Our findings show that KNUST has a policy for PBL which takes the form of projects conducted at the end of the fourth year. Nevertheless, awareness was low in the teaching participants but comparable in the educational managing participants. Education managers, teachers and students concurrently reported two prioritized needs for PBL, namely, connecting students to industry, and making materials needed for projects accessible and less expensive. However, in a large extent, these three groups had varied views regarding the needs. The differences in views reflect different aspects of needs from administrative, teaching and learning perspectives that could be tailored together to achieve an effective and robust PBL program within KNUST. And could also be used to guide policy review and informed decision making within the university. Further research that utilizes representative samples of Ghanaian higher education is worthwhile to aid national tertiary education policy for PBL.

Keywords: curriculum, pedagogy, practice, strategy, education

Contribution: Best Practice

1 Introduction

Problem-based learning (PBL) is widely recognized as an effective instructional pedagogy in higher education. Its pedagogical advantages include: exposing students to real-world challenges, higher-order thinking skills, interdisciplinary learning, independent learning, information mining skills, teamwork and communication (Ng, 2008). PBL originated from medical sciences, to respond to the criticism that the traditional teaching and learning method failed to equip medical students with problem solving-skills (Hung, *et al*., undated). Since the introduction of PBL at the School of Medicine, McMasters University in 1969, many medical schools in different parts of the globe have adopted this teaching methodology (Lee, and Kwan, 1997). At present, it has become popular across several study domains in higher education.

Graduate unemployment is an increasing problem in many countries, including Ghana. Adopting a new educational pedagogy that embeds students' learning processes in real-life problems could be a useful strategy to tackle this problem as it has the potential to acquaint them with the skills of modern jobs. This presupposes and underscores the necessity of incorporating PBL or PBL-like pedagogies into the curriculum of Ghanaian universities. In the context of this paper, we report on PBL in the setting of the Kwame Nkrumah University of Science and Technology (KNUST) in Ghana.
The primary objectives are to

- Investigate the available PBL policies and/ or strategies and awareness of teaching practices that include PBL.
- Outline the greatest needs regarding the introduction of PBL within the university.

Given this context, the research questions were the following:

1. Does the university/college/department have a policy and/ or strategy for introducing PBL or similar student centered teaching and learning? If yes, please elaborate – if possible get a written copy of the policy/ strategy. If no, do you think there is a need to get one?
2. Are you aware of any teaching practices including PBL or similar student centered teaching and learning within the university/college/department?
3. What are in your opinion the greatest needs for PBL or similar student centered teaching and learning within the university/college/department?

2 Literature Review

PBL is commonly described as a student-centered pedagogy where learners are actively engaged in real-world problems to solve or meet challenges (Correnti, *et al*., 2014). It is regarded as the most innovative pedagogical method conceived in the history of education (Hung, Jonassen, and Liu, 2008). In PBL, students have the opportunity to develop skills in reasoning and self-directed learning. It also allows students to work in collaborative groups to discover what they need to learn to solve a problem (Hmelo-Silver, 2004). Through this pedagogy, students learn how to solve problems that are ill-structured, open-ended or ambiguous (Ng, 2008). Hmelo-Silver and Barrows, (2006) explained ill-structured problems as complex problems that cannot be solved by a simple algorithm. In this context, students must define the problem, identify and acquire the skills and knowledge needed to solve it and work through the solution. In PBL emphasis is placed on the process of learning and the importance of recognizing the knowledge and skills required in solving a problem, rather than the content itself. In this framework, the teacher acts as a facilitator, and not a source of solutions.

With PBL, students need to access information, evaluate and select what is most relevant, then use what is selected. Students can access information through internet searches, online libraries or traditional textbooks (Acs distance education, 2015). Other information may be accessed via trips to sites (Ng, 2008). Several studies have researched the effectiveness of PBL. Among others, the conventional teaching and learning methods have been compared with PBL. In a recent meta-analysis study, PBL was found to be superior in terms of long-term retention, skill development and satisfaction of students and teachers, however, the conventional approach was more effective for short-term retention (Strobel, and van Barneveld, 2009). Besides, PBL has been well accepted as a successful strategy among teachers and students of higher education institutions (Ribeiro, and Mizukami, 2005; Surif, *et al.,* 2013). A website report on PBL indicates that there has been a strong trend of acceptance toward the use of PBL by many successful and progressive universities across the world; and graduates from this form of education consistently achieve better and progress faster in their careers than graduates from comparable traditional classroom-based education (Acs distance education, 2015).

Ensuring effective PBL entails achieving set goals. The goals of PBL include helping students develop 1) flexible knowledge, 2) effective problem-solving skills, 3) self-directed learning skills, 4) effective collaboration skills, and 5) intrinsic motivation, (Hmelo-Silver, 2004). Articulating policies and strategies could be vital to achieving these goals. For instance, Hmelo-Silver and Barrows (2006) in their study showed that an expert facilitator of PBL has strategies for meeting PBL goals and such strategies are also used to help new PBL facilitators to learn the art of facilitation. Tai and Yuen, (2007) have also demonstrated the usefulness of assessment strategies in a PBL setting. However, in their study, they showed that not all strategies worked properly in the PBL framework. An essential component in the success of PBL is the problem itself, as ineffective problem design results in failure of the learning process (Kukkamalla, *et al.,* 2011). Moreover, good facilitation of PBL requires proficiency in understanding the concepts behind learning theories (Coelho, 2014) and experiences and exposure industrial events and processes (Tik 2014).

3 Methods and Materials

Study setting and method of data analysis

Data used in this study is extracted from the KNUST-based Building Stronger University (BSU) phase two project which is a cross-sectional survey of a section of workers and students of KNUST. The survey was conducted in the year 2014 with well-structured questionnaires built from a proposed matrix for mapping PBL in developing countries universities under BSU (Okyere *et al.,* 2017). A total of 1145 participants comprising 1020 student and 125 workers were surveyed. The working participants were educational managers and teachers of the university. Among students, the target population was those at level 200, 300 and postgraduate level. Students were drawn from Colleges of Science, Agriculture and Natural Resources, Architecture and Built Environment, Health and Allied Sciences, Arts and Social Science and College of Engineering. They were engaged through focus group discussions in their various lecture halls. The educational managers were mainly Provosts and heads of departments of the university. Educational managers, teachers and IT experts were engaged individually in their offices.

The study uses qualitative and quantitative statistical techniques mainly in descriptive perspective, with data analyses performed using graphical procedures and the test of proportion. The test of proportion was used under the null hypothesis that the proportion of participants in a given group responding “yes” to a question is equal to 50%, compared to a two-sided alternative hypothesis. On this test, statistical significance is taken at p-value less 5%. Data preparation and graphical procedures were computationally implemented in Ms Excel. Also, the test of proportions was performed with MINITAB.

4 Results

The study is based on responses from educational managers (3.8%), teachers (6.1%) and students (89.1%) in the KNUST-base BSU survey. To gain insights into the current situation of PBL at KNUST, the survey participants were asked if the university has a policy and/ or strategy for introducing PBL. This question was meant for educational managers and teaching participants. Exactly one-fourth of the educational managers reported that the university has policy and strategy for introducing PBL. However, among the teaching participants, only 9.5% indicated that the university has policy and strategy for introducing PBL. However, these participants, both educational managers and teachers neither stated nor provided a written copy of the policy. From Table 1, the proportions of educational managers 25% (95% CI: 12.2%, 37.8%) and teaching participants 9.5% (95% CI:2.6%, 16.3%) who indicated that the university has a policy and/ or strategy for introducing PBL were significantly less than 50.0%. Among those who disagreed, there were positive concerns regarding the need for such policies.

Table 1: Test of Proportion for available Policy and/ Strategy for introducing PBL

	QUESTION: Does u/c/d have a policy and/ or a strategy for introducing PBL or similar student centered teaching and learning?			
Survey Participants	**Sample Proportion (%)**	**95% Confidence Interval**		**P-Value**
Educational Managers (n=44)	25.0	12.2	37.8	0.001
Teachers (n=70)	9.5	2.6	16.3	0.000

Furthermore, the participants of the survey were asked whether they are aware of any teaching practices that involved PBL or similar student centered teaching and learning activities within the university. On this issue, the majority of the educational managers (54.4%) indicated that they know teachers who exploit PBL in their teaching activities.

Table 2: Test of Proportion for Teaching Practices including PBL

	QUESTION: Are you aware of any teaching practices including PBL or similar student centered teaching and learning within u/c/d?			
Survey Participants	**Sample Proportion (%)**	**95% Confidence Interval**		**P-Value**
Educational Managers (n=44)	54.4	39.7	69.1	0.652
Teachers (n=70)	19.0	9.8	28.2	0.007

From Table 2 this corresponds to a p-value of 0.652, therefore suggesting that the proportion of educational managers who were aware of teachers utilizing PBL is not significantly different from 50.0%.

Among the teaching participants, 19.0% reported that they are aware of teaching activities that involve PBL. This proportion appeared to be significantly different from 50.0% (p-value=0.007). Survey respondents were asked to express in their own opinion the greatest needs concerning the introduction of PBL within the university. The responses to the question have been tabulated with their occurring frequencies in Table 3.

Table 3: Frequency Distribution of Participants by Prioritized Needs concerning PBL (N=1134)

QUESTION: What are in your opinion the greatest needs concerning the introduction of PBL within u/c/d?

Response Codes*	Educational Managers (n=44)		Teachers (n=70)		Students (n=1020)	
	Freq.	Percent	Freq	Percent	Freq.	Percent
NPBL1	6	13.6	17	24.3	58	5.7
NPBL2	14	31.8	8	11.4	380	37.3
NPBL3	11	25.0	19	27.1	401	39.3
NPBL4	11	25.0	24	34.3	366	35.9
NPBL5	21	47.8	27	38.6	438	42.9
NPBL6	10	22.7	14	20.0	613	60.1
NPBL7	9	20.5	17	24.3	73	7.2
NPBL8	4	9.1	12	17.1	44	4.3
NPBL9	0	0.0	15	21.4	473	46.4
NPBL10	0	0.0	25	35.7	464	45.5
NPBL11	0	0.0	0	0.0	32	3.1
NPBL12	25	56.8	34	48.6	467	45.8
NPBL13	22	50.0	14	20.0	39	3.8
NPBL14	0	0.0	0	0.0	481	47.2
NPBL15	29	65.9	33	47.1	537	52.6
NPBL16	21	47.7	37	52.9	205	20.1
NPBL17	20	45.5	26	37.1	497	48.7
NBPL18	26	59.1	30	42.9	552	54.1

*Labels for response codes can be found in the Appendix section

From Table 3, 65.9%, 59.1%, and 56.8% of the educational managers reported the need to create an enabling environment that can help connect students to the industries, making materials needed for projects accessible and less expensive, and give them access to laboratory apparatus and equipment, as the most prioritized needs concerning the introduction of PBL. Regarding the greatest need among the teaching participants, more than half (52.9%) indicated that there should be a subject-specific library, for each department. Other highly prioritized needs among the teaching participants include laboratory apparatus and equipment (48.6%), the connection of students to the industries (47.1%), and making materials needed for projects accessible and less expensive (42.9%). In the student participants, the first five greatest needs regarding the introduction of PBL are computers with reliable internet access (60.1%), making materials needed for projects accessible and less expensive (54.1%), the connection of students to the industries (52.6%), buses should be provided to convey students to problem site (47.2%), and more clinical and test laboratory with equipment should be made (46.4%).

5 Discussions

There is a vast literature regarding PBL as a successful pedagogy in education (Ribeiro, and Mizukami, 2005; Surif, *et al*., 2013; Acs distance education, 2015). As Silver and Barrows (2006) demonstrated, the adopting strategy helps in achieving PBL goals which are vital to attaining successful PBL environments. The present study is the first of its kind to examine issues about policy and/ or strategy as a key platform to the introduction of PBL in a Ghanaian university, precisely KNUST. The study employed responses gathered from educational managers, teachers, and students of the university. Our results show that KNUST has a policy for PBL. The PBL existing at KNUST takes the form of projects which occurs at the tail of the fourth year of undergraduate studies. However, the PBL practices within the university are constraint by inadequate human and infrastructural resources (Okyere *et al*., 2017) that could lead to suboptimal learning experiences in students. The participants viewed PBL as a valuable pedagogy and highlighted the need for an introduction/revision of policy and strategy for complete implementation. The results indicate that the educational managing participants who were aware of teaching practices incorporated with PBL did not differ significantly from 50%. Awareness in the teaching participants was significantly less than 50%. The less awareness among the teaching participants could be due to inconsistent conception or definition of PBL with the fourth-year project occurring at KNUST. It is very difficult to compare these results to those of other studies due to differences in data sources, study approach, study participants and inclusion criteria.

Despite the reported differences, some results correspond to the literature. The participants reported their greatest needs concerning the introduction of PBL within the university. The highly-rated ones include linking students to the industries, providing PBL libraries and computers with reliable internet access, buses for trips to problem sites, clinical and test laboratories, restructuring academic curriculum to suit the program, training for teachers, and making materials needed for projects accessible and less expensive. The need for buses for trips to problem sites and computers with internet connectivity are in accordance with the discussion on access to information in the PBL curriculum (Ng, 2008; Acs distance education, 2015). Moreover, textbooks are also sources of information in PBL (Acs distance education, 2015). As outlined, PBL libraries stocked with books could be a source of content knowledge of problems. Literature suggests that PBL is a student-centered pedagogy which allows students to learn through experience (Hmelo-Silver, 2004; Hmelo-Silver and Barrows, 2006; Correnti, *et al.,* 2014). Therefore, linking students to industries will enhance their exposure and their ability to understand and solve problems.

Conclusion

In our study we found documented policies and strategies describing the situation of PBL like practices at KNUST, although a few of the teaching participants were aware of this policy. When compared, the proportion of educational managers who were aware of teaching practices incorporated with PBL did not differ significantly from their counterparts who were not aware. However, awareness in the teaching participants was significantly less than 50%. The study demonstrates that the educational managers, teachers and students share some common thoughts on the needs for PBL, viz connecting students to industry, and making materials needed for projects accessible and less expensive, although there are many reported needs which did not match across these three groups of participants. The differences reflect different aspects of needs for PBL from administrative, teaching and learning perspectives which could be considered in tandem in reviewing PBL policy for the university. As PBL yields effective results than other comparable pedagogies (Ribeiro, and Mizukami, 2005; Surif, et al., 2013), we recommend its full implementation at KNUST, in Ghana higher education and beyond. However, a notable issue is that applying PBL could be very expensive so it could place a heavy financial burden on all stakeholders of education in developing countries. Universities and their students would require substantial support, particularly, from the government to embrace the full implementation of PBL. Our study paves the way for replicated studies with larger samples or many similar studies from African context to allow for generalizability and/or comparability of results.

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Appendix: Meanings of the Codes of the Greatest Needs for PBL

NPBL 1: A more conducive study space for teams

NPBL 2: Incentives for lecturers and students

NPBL 3: The need to restructure the university's course evaluation system.

NPBL 4: Renovate college libraries and furnish them with books.

NPBL 5: Restructuring of the academic curriculum to suit the program and the students

NPBL 6: Computers with reliable internet access

NPBL 7: More lecturers and facilitators should be employed

NPBL 8: Update the schools' information data base

NPBL 9: More clinical and test laboratory with equipment should be made

NPBL 10: Internship opportunities outside the country

NPBL 11: Reagents should be provided by the school

NPBL 12: Laboratory apparatus and equipment

NPBL 13: Training for teachers and laboratory technicians

NPBL 14: Buses should be provided to convey students to problem site

NPBL 15: Connection of students to the industries

NPBL 16: Specific PBL library to specific department

NPBL 17: Creating a forum for students to meet resource personnel

NPBL 18: Making materials needed for projects accessible and less expensive

Experience and reflections – implementing European teaching methods in 5 African Universities

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Abstract

This paper will discuss experience and reflections regarding implementing European teaching methods at African universities. The experiences and reflection are based on work in Erasmus project “Enhancing Entrepreneurship, Innovation and Sustainability in Higher Education in Africa” (EEIS-HEA) in Tanzania and in Ghana during 2019-2020. The EEIS-HEA project aims at enhancing the implementation of sustainability and entrepreneurship/innovation through student-centered learning and e-learning in five educational programmes. The trainers are allocated at five European Universities (Kwame Nkrumah University of Science and Technology, KNUST (Ghana), Kilimanjaro Christian Medical Center College, KCMUCo (Tanzania), Sokoine University of Agriculture, SUA, (Tanzania), University of Energy and Natural Resources, UENR, (Ghana), State University of Zanzibar, SUZA) and the method of training is based on a jigsaw model with training in Europe and Africa. Our perspective in this paper is primarily a teacher/ instructor perspective while acting as trainers of colleagues from our partner universities.

Our reflections will focus on internal and external opportunities and obstacles during the first educational part of the project. As for internal opportunities, the project has increased the network of European teachers at their University in a very positive way across teaching areas. As for external obstacles stakeholder expectations in terms of, for example, expectations from future employers and government institutions are important. At the internal university level both formal and informal institutions such as program development and issues related to project implementation will be discussed.

Finally, we discuss how trainers coming from a European educational system meet challenges and differences of concept and context disparities. In the case of teaching entrepreneurship and innovation, the European concepts of teaching is aimed at training for opportunity-based entrepreneurship and the vast majority of students with a higher-level education degree, does enter employment rather than entrepreneurship. In contrast, the African context is an environment where entrepreneurship is primarily necessity-based and a common source of self-employment.

Keywords: Curriculum design, Teacher Reflection, Culture Change, Student Centered Learning, Entrepreneurship and Innovation

Type of contribution: PBL practice

1 Introduction

In many parts of Africa, unemployment is high, even among the young people who have a degree in Higher Education (HE). To teach entrepreneurship, find solutions to local problems and needs - and think sustainably at the same time - is necessary in these regions. It is important that the European countries give support and knowledge to raise consciousness to ensure rapid and forward development contributing to societal development progress.

The Erasmus project "Enhancing Entrepreneurship, Innovation and Sustainability in Higher Education in Africa" (EEIS-HEA), started in October 2018 and continuing for three years. Five European Universities are facilitating development of teaching at five African universities in Tanzania and in Ghana. The participants of the project are KTH, Royal Institute of Technology, Stockholm, Polytechnic University of Catalonia, UPC, University of Copenhagen, UPCPH, Roskilde University and Aalborg University which also is representing as main project leader (European Universities) and Kwame Nkrumah University of Science and Technology, KNUST (Ghana), Kilimanjaro Christian Medical University College, KCMUCo (Tanzania), Sokoine University of Agriculture, SUA, (Tanzania), University of Energy and Natural Resources, UENR, (Ghana), State University of Zanzibar, SUZA (African Universities).

The aim is to increase faculty competence in four fields of education; Entrepreneurship and Innovation (E&I), Sustainability (SUS) and teaching methods such as Students Centered Learning and E learning (SCL and EL). This project is designed to reform five Higher Education (HE) study programmes aligned with local, national and regional needs and priorities, partly or fully redesigned in close collaboration with external stakeholders. The programmes are BSc. Aquaculture and Water recourses Management at KNUST, Bsc. of Science in Environmental health at SUZA, BSc. of Science in Information Technology at SUA and BSc. of Renewable Energy Engineering at UENR. More information about the project is available at the project website: https://eeishea.sites.ku.dk/

This paper evolves from discussions among project members at Royal Institute of Technology, KTH, in Stockholm regarding the first (educational) part of the project and our European university context. We were intrigued and puzzled of both the similarities and the differences at our fellow Universities in Africa. We noticed differences in several fields; cultural, formal and informal processes, decision-making, but also that there is context and concept disparities regarding what we mean with entrepreneurship and innovation. How would this environment, both the academic environment as well as financial and living conditions, affect the educational support we were meant to provide? It is already a challenge to implement effective projects managing European culture differences. Though we believe that our project and its European colleagues aim for the highest impact this paper can give some insights into how a fruitful collaboration between Europe and Africa can be improved. We would like to point out that said reflections are not the official view of the project, but rather the authors' view of a collaboration overseas. With this paper we would like to provide an experience-based approach to implementation of European teaching methods in African Universities. However, the complexity of the implantation process (and the scope of this paper) implies that we at this stage do not aim to provide a framework for educational collaboration in this context.

2 Pedagogical framework

HE's educational environment has been evolving over the decades and will continue to do so. Research on teaching for HE's is increasing and shows the importance of varied teaching to help students reach the intended learning outcomes (ILO). Student Centered Learning (SCL) (Elmgren, and Henriksson, 2014) is a teaching method that puts the student in focus and is a central part of the project.

Two SCL methods are implemented in the project, Problem Based Learning (PBL) (Biggs and Tang 2007) and Challenge-Driven Education (CDE) (Magnell and Högfeldt, 2015). The starting point for learning is a problem and by solving a problem, or a series of problems, the learning itself begins. The learner seeks knowledge and understanding to be able to find a solution. For students to solve problems with a CDE- approach, the context and problem should originate from socio-technical and real life challenge. CDE, or Challenged-Based Learning, which is more or less synonymously, address learning outcomes related to sustainable development. (Rosén, Högfeldt el al 2018). These two components are well suited for this project in the African context.

During the first phase of the project training simultaneously took place in Europe. The training is based on a Jigsaw teaching technique where the group of participants are divided into teams which is called the Home Group (HG). The participants in these teams should be heterogenous and has a joint assignment to solve. The team is then split, and each participant will join a second team, an Expert group (EG) to share their knowledge about the assignment. (See fig 1).

In the EEIS-HEA project the Home Groups are the five African Local Task Force (LTF) teams. They have to jointly re-design a study program curriculum, integrating relevant elements of the educational areas of E&I and SUS, while delivering the curriculum through the use of relevant SCL-approaches and applying relevant E-learning tools. The Expert Groups therefore are the four training teams where focus is on the areas: SCL, E-L, E&I and SUS. Each African university has appointed 2 participants, one main and one assisting, to each training team, for being able to support each other. After being trained in two European workshops, they returned to the LTF teams (Home Group) where they are in a third and final face-to-face internal training workshop taught each other, thus drawing on the strength of peer teaching.

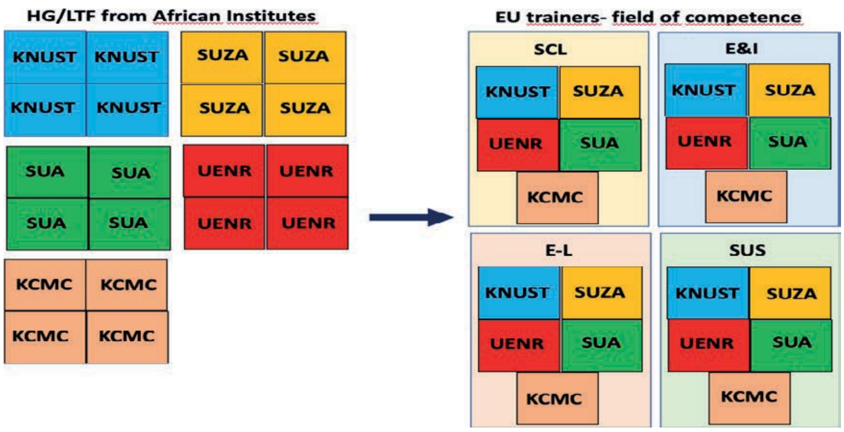

Figure 1 Jigsaw teaching technique

Figure 1 illustrates this the method of Home and Expert group. You can find more information about the Jigsaw Classroom here: https://www.jigsaw.org/

The sources used for supporting this paper consists of the working material in the project such as minutes, reports, individual reflections and discussions.

3 Internal opportunities and challenges

When we reflected on our experience of participating in the project so far, we identified both issues relevant for our own and our African partners internal processes and internal environment. Other issues were more related to external demands such as programme of curriculum development and institutions e.g. from stakeholder outside of the university.

3.1. Collegial perspective

Among the trainees from the African university, three universities (SUA, SUZA and KCMUCo) faculties and their students have been exposed to SCL and E-L-methods in previous educational projects that they have been involved with. Hence, it was possible for them to comprehend the issues discussed by the EU trainers from different perspectives. This provided them insights on how different institutes in EU integrate issues such as SCL, E-L, E&I and SUS in a more innovative and creative way and thus putting them into practice. Prior knowledge and experience in various areas was also discussed with trainers in order to bring the ideas to the next level and eventually implement them at an institutional level. The skills learnt from E-L equipped them to learn more and motivated them to adapt the knowledge to their situation. Since they have prior knowledge and received relevant training in this program, it is easier for them to implement the above- mentioned specializations with minimal resources. They are very well aligned with national and global demands in terms of SCL, E-I and SUS approaches. These institutes are ahead in providing mandatory pedagogical courses for their staff, as well as investing in and improving the learning environment such as space, ICT-facilities and human resources.

The other two universities (KNUST and UENR) had little or no prior knowledge in the four training areas. Thus, the project provided an arena to introduce the ideas of SCL, E-L, E&I and SUS. It provides an opportunity to learn how EU universities apply various skills and integrate them in higher education whilst being equipped with the appropriate infrastructure. Though the concept of SUS is known it was not put into practice in the education. The training provided a new insight in executing these activities in their curriculum.

The peer training among the trainees before each workshop served as an opportunity for them to understand the concept more effectively during the training program. The trainees took forward the rudiments of, for example, SCL to their colleagues to implement them at an institutional level. The training also presented them a platform to interact with EU trainers and colleagues from other African universities and share valuable information. Furthermore, it provided immense knowledge to the process of re- designing a curriculum. This expertise is an added value in the program that they can learn from other universities though there might be differences between EU and Africa in terms of formal and informal challenges.

In addition to the two days of training in the subject area, two days of the programme at the European universities was devoted to visits and excursions to relevant infrastructure facilities, organizations and interaction with students. The E&I training programme at KTH included, for instance, visits to KTH innovation, Greenhouse labs and STING (Stockholm Innovation and Growth). Some universities highlighted the difficulties encountered in applying the knowledge from EU due to a lack of this type of infrastructure facilities like innovation centers, incubators, museums, support from organizations etc., which could be a challenge for the students to think outside the box.

The training program stimulated interactions within African universities and encouraged an exchange of ideas and thoughts to initiate the process of implementation at all levels (colleagues, department, institution management, curriculum and at the education ministry etc.,). Hence, continuous collaboration between trainers and African trainees could trigger foster knowledge sharing for implementing activities.

This was noticed when the trainees attended the third workshop which took place at their home university, in which all trainees reflected on their knowledge on how to address and implement the activities learnt during the program. This program provided the platform by initiating networking of the trainees in order to learn from each other, share the common hurdles and find a suitable process to execute the activities.

3.2. Extended network for European trainers

By using the Jigsaw method there is a positive outcome in extended networking for those involved. New contact paths have been created within each university, between internal institutions, two continents, five countries and ten different universities. The number of combinations for new collaborations is vastly. The extended network is also naturally spread in a very broad range of positions and teaching areas derived from various academic environments. Despite benefits of an expanded network overseas, we should not underestimate the importance of the internal network of the teachers from KTH taking part in the project leading up to writing this paper. The authors have gained a broader collegiate network, access to new knowledge; and in-depth knowledge of educational teaching methods. The African network has provided us with the necessary insight on development in third world countries, which could not have been obtained through digital contacts alone. The network will hopefully continue to be fruitful throughout the project and form the basis for new research and development collaborations. However, we find it contradictory to multiple long distance travelling, which might not support the environment and climate aspect.

4 External opportunities and challenges

4.1. Involving external stakeholders in the programme development process

Stakeholder identification and management are important for management, decisions making and planning strategy and are key to the success of public sector organisations (Bryson 2004) and can also be applied higher education institutions (Chapleo and Simms, 2010). Higher education stakeholders may, for example, include students, alumni, staff, suppliers, communities, industry professions, potential employers, governing entities, joint venture partners (e.g. Burrows, 1999, Chapleo and Simms (2010).

In the European context, stakeholders voluntarily participate in the process of development in higher education, programmes and strategies without any pecuniary compensation in return for their time invested. Their return consists in contributing to the relevance of the content of higher education, as well as potential recruitment of employees. At KTH, several large established firms have a long–term commitment and history of contributing to strategic development as well as providing current cases, problems and thesis topics that are relevant and can be used in problem-based education setting. Furthermore, this long-term relationship has generated trust in the skills, competences and abilities that these firms can expect our graduates to obtain. In general future employees do not ask for detailed information about the content of the students' education. However, involving stakeholders in the EEIS–HEA project on a voluntary basis has turned out to be difficult. In order to actively involve stakeholders' pecuniary returns needs to be introduced in order to, for example, involve entrepreneurs in the process. Hence, a challenge is how to establish stakeholder links, which provide industry relevant problems, and cases which clearly contribute to the development of their ventures?

Furthermore, as for the EEIS–HEA project, we experience that external stakeholders want the higher education institutions to provide quite detailed information about the content of the education programme. Hence, we perceive that there is a need to document students' knowledge in terms of content at a much more detailed level. This constitute a difference since implementing PBL may result in formulating intended learning outcomes and competences which more broadly defined such as, for example, student's having problem solving skills. How can stakeholders be informed and learn to trust the competences that the students now will have is a challenge.

4.2 Changing the programme curriculum

We believe that, with KTH as point of reference, the European process of curriculum changes is more moderate than with the African partners. We will discuss below two areas where we perceive tangible differences, formal and informal institutions.

The formal process under discussion will be the choice of decision makers and the number of levels of accreditation that a recently created program must pass. A clear difference is that the Tanzanian validation process has several levels compared to the formal process at KTH. The process in Tanzania include external decision-makers, unlike the process at KTH which mainly contains internal parties. Since this project focus on a program level, it's important to have these differences in mind when you design a project and estimate time for delivery. The process in Sweden is lengthy but the African process is probably moreextensive.

Another reflection on the African method regards the involvement of external decision-makers in the validation process. The Swedish process (at KTH) contains internal validation and decision-makers with the university headmaster acting as last instance, while on the other hand the African Process (at KCMUCo), is more extensive and contains external institutions.

The external institutions in the Tanzania accreditation process consist of stakeholders and Tanzania Commission for Universities (TCU), acting as last instance. The TCU is an institution for quality insurance in Tanzania. Any university has to be validated to operate in Tanzania. So far, there are 43 Universities, Colleges and other institutions which have met or exceeded the minimum standard of quality (TCU website www.tcu.go.tz). At Swedish universities there is a natural and ongoing process for communication with external partners, such as stakeholders, for course- and program development, but no formal decision point for them in a course/program approval process. Stakeholders are generally taking part of program councils, school councils and having continuous participation in project courses and as guest lecturers. External partner from working life does not have the same goals as universities and, in our opinion, does not have a natural part as a decision-maker in the process of a new program. Their involvement in an initial and developing phase/process within the subject is obvious but not in the approval phase. There could be a risk for decisions being based on market forces rather than the development of the learning environment. We believe that if stakeholders and government commission would take part of the approval process, they would need an early engagement in the project and gain an understanding of curriculum design for decision making about programdevelopment.

The informal processes at KTH, implies that the Director of studies for each programme is continuously involved in the development of the program. According to Swedish and KTH quality regulation, each course is stipulated to provide a course evaluation to find out the students' opinions. A course evaluation is an important tool for the teacher to perceive and apprehend if the students reach the intended learning outcomes for the course. The evaluation will also give insights for course development. During a progressive course development, the evaluations can indicate less satisfied students, which does not however, mean that the course has become poor, it can simply show students' uncertainty of new teaching methods. It's important to allow the development of a curricula to take time and that the Director of studies can allow temporary drops in the evaluation result. In the African context there seems to be a lower tolerance at the formal level to accept a critical evaluation during times ofchange.

5 Concept and context disparities of entrepreneurship andinnovation

Formal and Informal institutions, where informal institutions are, for example, customs, norms and social networks. Formal institutions are, for example, political and economic prerequisites such as polity, judiciary and bureaucracy are important for determining if and which entrepreneurial activities that are going to take place in different cultures and contexts (Baumol, 1990; Wennekers et al. 2002; Nyström 2008). The institutional context, prevalence, and characteristics of the entrepreneurial actives differs in the European and African context, which influence the training activities in entrepreneurship and innovation in the programme. Figure 2 display differences in levels and characteristics of entrepreneurial activity. In Sweden and EU, about 8 percent of the population are entrepreneurs while in Ghana and Sub-Saharan Africa about 25% of the population define themselves as entrepreneurs. Opportunity- based entrepreneurship refers to entrepreneurs who has identified a business opportunity which they want to explore necessity-based entrepreneurs are pushed into starting a business since they lack other options in the labor markets. In Sweden, most entrepreneurs are opportunity-driven, while 30 percent of the entrepreneurs in Ghana and Sub-Saharan Africa are necessity-based entrepreneurs.

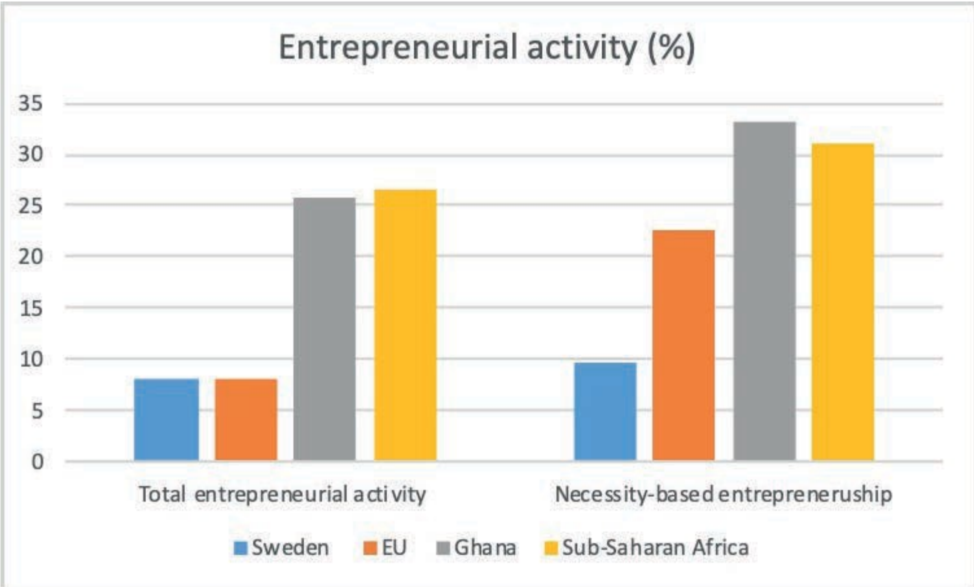

Figure 2: Entrepreneurial activity (Source: GEM, 2014

(We choose to present figures from the Global entrepreneurship monitor (GEM) for 2014 (data for 2013) since this is the last year that figures for Ghana is available. Unfortunately, Tanzania does not participate in the GEM-project)

Figure 3 displays entrepreneurial attitudes in the EU and sub-Saharan Africa contexts respectively. What characterizes the Sub-Saharan region are high levels of optimism, with a large share of the population who perceive good opportunities to become an entrepreneur and that they have the capabilities for it. Actually, the figures for perceiving good opportunities in Ghana is among the highest in the region, GEM, (2012b). In Sweden and EU less the pollution to less extent think, they have the capability and largely are afraid of failure. What are the implications of these differences for entrepreneurship an innovation training of students? In the European context unconsciously equalize entrepreneurship with opportunity–based entrepreneurship and that is what our teaching and training is aimed at. In addition, the vast majority of students with a higher-level education degree enter employment rather than entrepreneurship. After graduation, only 3 percent of KTH graduates become self-employed and the unemployment rate is very low at 2 percent (KTH, 2018). In contrast, the African context is an environment where entrepreneurship is primarily necessity-based and a common source of self-employment.

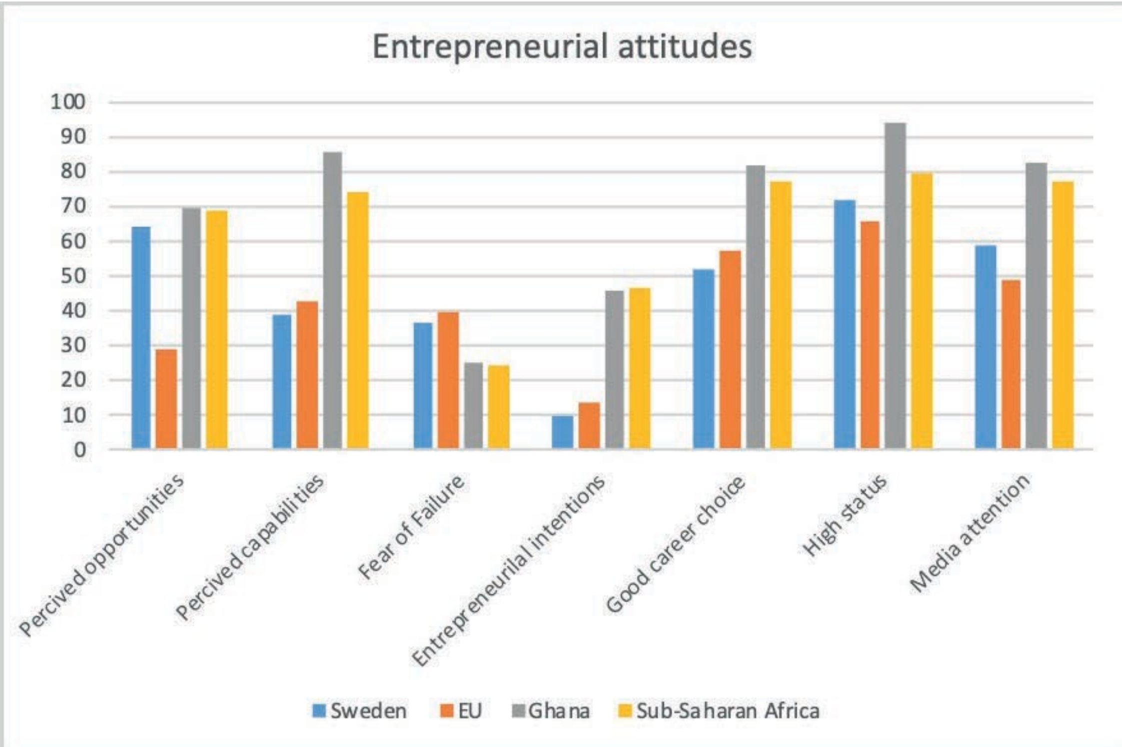

Figure 3 Entrepreneurial attitudes (Source: GEM, 2013)

As regards formal institutions related to doing business Sweden ranks number 10 when the World Bank compares different dimensions of the ease of doing business across countries. In comparison, Ghana ranks 118 and Tanzania ranks 141 out of 190 countries. (World Bank, 2020). When asking the Swedish population only 25 percent perceive that it is easy to start a company (Nyström, 2013). However, a lot of information is easily available through web pages and for example the tax authority. Our entrepreneurship training at HEI's put very little emphasis on how to manage these formal rules of the game. We experience that the demand for this type of information and training is more pronounced among our African partners and nothing that we are able to support since it is very local and country knowledge that isneeded.

6 Final remarks and reflections

The training in the project is based on the jigsaw method. However, we as trainers are not "jigsawed" with having little knowledge about the other areas of training. The fact that we were not "jigsawed" may influence the fit, sharpness, and subsequent alignment of the jigsaw technique pieces delivered in the project. As trainers, you would like to have an idea about how the different pieces should look like in the end in order to provide pieces that fits into the jigsaw puzzle.

The common set-up for this type of education project is that have trainers come to the African universities to perform the training there. This project had a different approach providing the initial training in the European institutional context. We believe this has been important for trainees understanding the institutional framework of our teaching methods and approaches and helps them selecting what could be doable in their context. Coming to KTH and, for example, visiting the KTH innovation and STING-incubator does not only provide participants with unique experience and motivation, but also helps sharpen their arguments when working for improving their institutional conditions in their context.

Finally, we are well aware of that the project has indeed generated a number of travels between Europe and African countries, and one may ask if this is necessary, in particular from a sustainability perspective. However, we experience that some things cannot just be equally efficiently experienced over internet. For instance, we perceived that it was important for our trainees to actually visualize how a library prepared for self-studies look like or for EU trainers to see and meet the entrepreneurs of a fish farm in Ghana. We have also experienced that some of the communication tools that we take it for granted works well in our context (e.g. Skype, Zoom) might not for technical reasons work sufficiently well in the African context. Finally, we experience that these face-to-face meetings also ensure that participants can able to devote a sufficient amount of time to the project and motivated to implement the strategies in their home institutions.

In the next phase of the project, our challenge will be to help and support the implementation of the jigsaw teaching method at the five universities and subject fields that are under curriculum review within the framework. This implies a substantial complexity where the final outcome is yet to be seen. Nevertheless, the project has introduced learning and skills associated with the ideas of SCL, E-L, E-& and SUS at our African partner universities.

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PBL Implementation – Experiences and Workflows

Crafting Design Problems for Project-based Learning in First-year Undergraduate Engineering Education

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Abstract

Engineering Education has to prepare students for solving workplace problems. Practising engineers commonly solve design problem, troubleshooting problems, system-analysis problems and decision-making problems which are ill-structured. Project-based learning and Problem-based learning pedagogies are adopted in engineering education to develop competencies required in solving such problems.

Success of these pedagogies depends on how well the problems are crafted. Though literature describes how to craft problems for problem-based learning pedagogy crafting design problems for Project-based learning in a design course needs exploration. The proposed work addresses this research gap using an existing framework of problem difficulty to analyse a set of chosen design problems. These problems are created for a first-year, undergraduate engineering course titled “Engineering Exploration” that uses Project-based learning pedagogy. Students design a Mechatronic prototype following engineering design process.

As per the framework, problem difficulty has two dimensions: complexity and structuredness. Complexity refers to the breadth of knowledge, the difficulty level of the concepts, relational complexity, and intricacy of problem-solutions steps. Structuredness arises from intransparency, interdisciplinarity, heterogeneity of interpretations, dynamicity, and legitimacy of competing alternatives. Results show that these characteristics of problem-difficulty are also applicable for crafting interdisciplinary design problems. The present study also unravels the elements that can be used to identify a-priori the level of complexity and ill-structuredness in design problems. These elements can be used to craft design problems with a known level of problem difficulty which is also attainable by students.

Keywords: Design Problem, interdisciplinary, Problem crafting, Project-based learning

Type of contribution: PBL research paper

1 Introduction

The curriculum and learning experiences in engineering education have to focus on the knowledge, skills and values that will prepare students to solve workplace problems. Practising engineers commonly solve design problems, troubleshooting problems, system-analysis problems and decision-making problems. These types of problems are complex and are essentially and ill-structured (D. H. Jonassen, 2000). To develop competency in solving such problems, pedagogies like Project-based learning and Problem-based learning are designed around ill-structured problems and are adopted in engineering education (Jonassen, 1997)(D. Jonassen et al., 2006). PBL assumes the centrality of problems to learning. These problems should embody the core constructs expected from successful learning: knowledge and skills; must enable the demonstration of behaviours that reflect the constructs; should be difficult and attainable at the same time. Crafting such problems is a challenging task.

As we set forth to understand what it takes to craft problems for PBL pedagogy, we came across two popular frameworks: 3C3R Model-A Conceptual Framework for Designing Problems in Problem-Based Learning (Hung, 2006) and the Design Problem Framework: Using Adaption-Innovation Theory to Construct design Problem Statements (Silk, Daly, Jablokow, Yilmaz, & Berg, 2014). However, how to craft design problems for Project-based learning in a design course at first-year undergraduate engineering is a grey area. The research question under focus is, “How to craft design problems for inter-disciplinary design experiences for Project-based Learning in first-year undergraduate engineering education?” To address this research gap, the proposed work operationalizes the theoretical conceptualisation of problem difficulty (Jonassen & Hung, 2008) to craft design problems for first-year undergraduate engineering design courses.

The context of the proposed work lies in a first-year, interdisciplinary design experiences course titled, “Engineering Exploration” at KLE Technological University (Baligar, Kavale, Kaushik, Joshi, & Shettar, 2018). The course follows Project-Based Learning pedagogy and student teams follow the engineering design process to design a mechatronic prototype.

2 Related Literature

This section examines previous work related to the concepts used in this paper. The intention is not to present an exhaustive and critical analysis, but to introduce the core and underlying concepts which, the authors hope will be enough to scaffold the proposed work on.

2.1 Problem-solving and Design Problems

“In everyday life, we constantly solve problems”. This truism comes from Karl Popper’s book All Life Is Problem Solving (Popper, 1999). Cohering with this thought is what Jonassen (2004) said, “Learning to solve problems is the most important skill that students can learn in any setting. In professional contexts, people are paid to solve problems, not to complete exams”.

Several instructional design techniques like Problem-based learning, Project-based learning, and Case-based learning have been introduced in education (Nelson, 1998) and particularly in engineering education (Du, Graaff & Kolmos, 2009). Project-based learning, which is the focus of the proposed work, is defined as an instructional design that organises learning around projects. Projects are complex tasks, based on challenging questions or problems (Thomas, 2000) that create opportunities for students to develop workplace competencies (National Research Council, 2013) as mandated in terms of twelve graduate attributes in Washington Accord (Accord, 2013).

Project-based learning is commonly driven by a class of problems called as design problems. A design problem is a statement of the requirements, needs, functions, or objectives of design (Ameri, Summers, Mocko, Porter, 2008), which are one among the four classes of problems solved by practising engineers These problems are ill-structured and complex and need extensive collaboration to solve (Jonassen & Hung, 2008). Literature is replete with studies on design-centric engineering education (Stojcevski, 2014; Han, Cook, Mason & Shuman, 2018) and how it is planned across the four years through a spine or continuum (Davis & Trevisan, 2000; Frank et.al., 2018; Schaefer, Dirk, Coates, Graham, Eckert, Claudia, 2019).

2.2 Problem-crafting and existing frameworks

The way a problem is structured and perceived by designers impacts the resulting outcomes, whether the context is education, research, or the workplace. In real-world, design problems are open-ended, ill-structured and complex (Dorst, 2006). In education, open-endedness, ill-structuredness and complexity need to be infused in the design problems so that the problem-solving experience is approximate to real-world problem-solving. Hence, in engineering education, instructors need to create statements of design problems that influence the process followed, outputs generated and outcomes attained by the students.

According to the Design Problem Framework (Silk et al.,2014), the design problems must include the following

i. A brief context about for whom and for what purpose a solution is needed,
ii. A statement of the need that specifies the functional requirements and constraints on acceptable solutions
iii. A description of the goal, including the general instructions and criteria to use in evaluating ideas.

An application of this framework leads to design problems spanning three frames: neutrally framed, adaptively framed, and innovatively framed. This framework offers overarching prescriptions on how the design problem should be. However, the authors found it of limited application for the proposed work, as its focus is on studying how constraints and criteria in the design problem influence an individual's ideation behaviours.

The focus of the proposed work is to evaluate design problems for their difficulty. Thus, the work by Jonassen and Hung (2008) has been chosen as a reference as it provides a framework to understand problem difficulty. This framework is applicable for Problem-Based Learning and problem difficulty is dissected along two dimensions namely complexity and structuredness. These dimensions are used to analyse design problems, diagnosis-solution problems, situated cases/policy problems and decision-making problems. The proposed work addresses the research question "How to craft design problems for interdisciplinary design experiences for Project-based Learning in first-year undergraduate engineering education?" It uses two of the four characteristics of complexity dimension and all characteristics of structuredness dimension mentioned by Jonassen and Hung as listed below: -

A Complexity of Problems

i. The breadth of Knowledge Required
This parameter refers to the vastness of the domain knowledge required to solve the problem and knowledge includes factual information, concepts, principles, and procedures needed for solving the problem

ii. Relational Complexity
Relational complexity is proportional to the number of relations and the number of attributes in the relations that need to be processed in parallel during a problem-solving process.

B Structuredness of Problems

The structuredness of a problem is the degree to which the ideas in the problem are known or knowable to the problem solver. The parameters to assess the degree of ill-structuredness are

i. Intransparency

The higher the degree of intransparency (that is, the more we do not know about the problem), more ill-structured the problem is. On the other hand, well-structured problems have a well-defined initial state, a known goal state or solution, and a constrained set of logical operators (a known procedure for solving) (Jonassen, 1997).

ii. Heterogeneity of Interpretations
The second parameter of structuredness is described by the number of possible interpretations and perspectives for understanding or solving the problem. The problem may be open for interpretations in terms of its initial state (what is the problem?), goal state (what is trying to be achieved?), and constraints (what are the rules or barriers?).

iii. Interdisciplinarity
When a problem requires interdisciplinary knowledge or considerations to solve, two crucial tasks are to identify all disciplines that contribute to the solutions and be prepared to solve the emergent issues that arise due to interdisciplinary interactions.

iv. Dynamicity
This parameter refers to the state of flux that exists in the problem space, goal state and operators which are dependent on the decisions made or actions were taken by the problem solver. These often emerge during the later stages of the problem-solving process.

v. The legitimacy of Competing Alternatives
This parameter refers to the extent to which the number of conceivable options for executing operators in various states and solution paths exists within the problem space. First, it increases the uncertainty of confidence in selecting the best solution to the problem. Second, it increases the number of tasks and time needed for validating and evaluating the options or alternatives for selecting the most viable solution paths.

3 Methodology

The proposed work addresses the research question, “How to craft design problems for interdisciplinary design experiences for Project-based Learning in first-year undergraduate engineering education?” Subsequently, the authors discuss the problem space, data collection and analysis methods.

3.1 Problem Space

The proposed research study originates in a first-year undergraduate engineering course titled, “Engineering Exploration”. This course is designed by a multi-disciplinary team of faculty members and was offered for the first time during 2015-2016. Currently, the course is offering its tenth delivery. This course offers interdisciplinary design experience to approximately 1200 first-year students through Project-Based Learning pedagogy (Baligar, Kavale, Kaushik, Joshi & Shettar, 2018). The enduring outcomes (Wiggins, & McTighe, 2005) of this course are the engineering design process, interdisciplinary nature of engineering problem-solving, and teamwork and collaboration. The content focuses on Engineering Design (Kaushik, Baligar & Joshi, 2018), Mechanisms (Kavale, Baligar & Joshi, 2018), Platform-Based Development, Engineering Ethics (Baligar & Joshi, 2017), Sustainability and Project Management. The output of this design experience is a mechatronic prototype as the solution for the problem definition students’ team carves out for the chosen need statement.

3.2 Current approach to crafting problems

In “Engineering Exploration” course, the instructors craft design problems keeping interdisciplinary nature of engineering problem-solving as the core enduring outcome. This is in-line with the concept of pre-authentication put forth by (Jonassen, 2011) stemming from the discussion on how to simulate real-world problem-solving in learning environments (Barab & Duffy, 1998). The design problems demand the application of knowledge and skills of electronics, mechanisms and programming corresponding to sensing, actuation and control of a mechatronics system. Each team of students works on chosen design problem whose solution is mechatronics system.

To evaluate fitness for use in the course, these design problems were evaluated using the following criteria: complexity, feasibility and diversity (in terms of possible alternative solutions). However, the following gaps are observed in this approach:

1. The definitions of complexity, feasibility and diversity are not theoretically based.
2. These criteria are based on the course instructor's collective and evolving understanding, feedback from students and observation of the mechatronic prototypes over the past five years of course delivery.
3. The current framework for creating design problems is not "shareable".

3.3 Data Collection and Analysis

The objects of study are design problems crafted for interdisciplinary design experience at first-year undergraduate engineering. A sample of 21 design problems that were crafted during the previous three years of the course delivery is considered for analysis. The design problems are included in Annexure 1.

To analyse the sample, Jonassen and Hung's (2008) framework of problem difficulty is used. The dimensions of complexity are described in section 1.1 and listed in Table 1. As stated earlier as well, of the four parameters of complexity, only two are used for analysis, while, all five parameters for structuredness are used. For each of the design problems, the process of analysis is detailed subsequently.

Table 1 Parameters for analysis

Complexity of Problems	Structuredness of Problems
1. Breadth of Knowledge Required 2. Relational Complexity	1. Intransparency 2. Heterogeneity of Interpretations 3. Interdisciplinarity 4. Dynamicity 5. The legitimacy of Competing Alternatives

A. Analysis of complexity for Breadth of knowledge

According to Jonassen and Hung (2008), breadth of knowledge is dependent on how much domain knowledge the problem solver needs to solve the problem. This knowledge includes factual information, concepts, principles and procedures needed for solving the problem. This definition is originally applicable to problem-based learning. For design problems, this conception is not sufficient and needs to be reinterpreted, as design problems also require artefact creation. This agrees with previous literature on solving design problems (Thomas, 2000; Fors, 2003; Gero, 1990). Thus, for the analysis of the sample design problems, the authors have reinterpreted breadth of knowledge as knowledge and skills required to fabricate the artefact, which is explained in detail later.

B. Analysis of complexity for Relational complexity

According to Halford, Wilson and Philips (1998), relational complexity is described as the number of relations that need to be processed in parallel during a problem-solving process. Jonassen and Hung (2008) argue that more complex the relations and attributes of the relations are in a problem, the more processing load is required during problem-solving, and as a result, more complex the problem is.

For design problems, it is necessary to identify the relations and attributes due to which relational complexity appears. The authors have studied this parameter from the perspective of the number of tasks (functions or processes) and their dependencies demonstrated in the artefact or prototype. Functional dependency can be depicted using a solution-graph.

A solution graph is a graphical exemplification of the functions appearing in the solution. Each node in the graph is a function and the arrows show the interdependency between the functions. The graph depicts the instructor's perspective of the possible functions and may not include all functions exhaustively. They are approximate to achieve the goal state. Example of a solution graph is shown in figures 1, 2 and 3 of section 4.2. Using solution graphs as a representation, the design problems are analysed in terms of in-degree for a function and the type of control system developed.

C. Analysis of Structuredness

According to Jonassen and Hung (2008), structuredness of a problem arises from the number of unknown elements in the problem. Structuredness is characterized by five parameters: intransparency, heterogeneity of interpretations, interdisciplinarity, dynamicity, and legitimacy of competing alternatives as described in section 2. The same has been used to analyse the sample design problems.

4 Results and Discussion

The proposed work investigates the research question, "How to craft design problems for inter-disciplinary design experiences for Project-based Learning in first-year undergraduate engineering education?" This section describes the results obtained from the analysis of 21–design problems for the dimensions of complexity and structuredness in sections 4.1, 4.2 and 4.3.

4.1 Breadth of knowledge

For design problems, the authors have reinterpreted breadth of knowledge as knowledge and skills required to fabricate the artefact. This concurs with previous literature. In a Project-based learning course, though some knowledge and skills will be imparted in a course, the need for learning and application of new disciplinary knowledge is inherent in the pedagogy. If the central activities of the project present no difficulty to the student or can be carried out with the application of already-learned information or skills, the project gets reduced to an exercise, not a PBL project (Thomas, 2000). Congruent to the findings, design problems vary concerning the additional knowledge and skills required.

Further, design problems have an additional layer of difficulty as their output is a physical artefact. This is a distinguishing feature between project-based learning and problem-based learning. To solve design problems, students generally build a prototype which satisfies the objectives, exhibits the functions and adheres to the constraints imposed upon the solution. From a theoretical perspective, the prototype serves as an external manifestation of ideas and is a public entity. It is an embodiment of knowledge and can be subjected to discussion, improvisation and critique (Fors, 2003; Gero, 1990). Creating prototypes depends on the availability of the parts or components. If the parts are not readily available, then it is necessary to estimate the cognitive load required to model and fabricate the parts.

Accordingly, a careful study of the prototypes developed for the selected design problems was done based on which we were able to classify these design problems into four categories The four categories represent different levels of difficulty as shown in Table 2 along with examples.

In table 2, the projects belonging to category B1, like pet dog bot, classroom cleaner are close to exercises and do not pose any challenge to students or instructors (for mentoring). During the first two deliveries of "Engineering Exploration", many design problems belonged to this category. However, the projects belonging to the B2 category did not need any additional knowledge, but the parts required to build the prototypes were not readily available. Hence material selection, modelling, and fabrication took the centre stage. For such projects, it is essential to have a prototyping facility. In the author's institute, Thinkering Lab is a low-cost prototyping facility that houses equipment and services, and mentoring specifically suited for this course. During the initial years of the course delivery, several initiatives were designed in the Thinkering lab to develop prototyping skills of first-year undergraduate engineering students. Kavale, Baligar, & Joshi (2018) have described one such attempt to promote the use of engineering methods as so to improve the reliability and performance of the mechatronic prototypes.

Table 2: Results of analysing design problems for complexity

Categories	B1	B2	B3	B4
Findings	The design problems were solved by applying concepts included in the syllabi and the prototype was built using existing parts.	The design problems were solved by applying concepts included in the syllabi Majority of the parts required for the prototype were not available as standard parts and were fabricated.	The design problems necessitated self-learning of one to two new concepts which were specific to the design problem. Majority of the parts required for the prototype were available as standardised parts.	The design problems necessitated self-learning of one to two new concepts which were specific to the design problem. Majority of the parts required for the prototype were not available as standard parts and were fabricated.
Examples of design problems	1. Oscillating toy horse 2. Classroom cleaner 3. Pet dog bot 4. Coloured cube sorting machine 5. Musical robot	1. Musical Bots 2. Cup crusher 3. Snacks and spice mixing machine 4. Robo soccer 5. Wire cutting and stripping machine 6. Board cleaning machine 7. Pattern printing machine	1. Paper aeroplane folding and launching machine 2. Automatic shoe polishing machine 3. Missile launching machine 4. Assistance to Divyangs 5. Gesture controlled bot	1. Game machine 2. Roasted groundnut peeling machine 3. Six/Eight legged walking robot 4. Carrom robot

In table 2, the projects belonging to category B3, like shoe polishing and missile launching machine were learning-intensive as they needed certain mechanisms like gears and springs, and flex sensors that were not taught in the course. As an estimate, the students spent some 25% extra time in learning new concepts and skills for projects. However, for category B4 projects, neither was course-knowledge sufficient nor the parts were available. Hence, these posed the highest cognitive load for students. For both B3 and B4 projects, faculty mentoring was pivotal in the completion of the projects. Frequently, student motivation wavered. For such projects, the faculty would identify learning needs a-priori and curate appropriate learning materials that would be eventually given to students. If necessary, instructors were equipped through workshops.

Of the 21 sample design problems, 5 projects belonged to B1 belonged to category, 7 belonged to B2, 5 belonged to B3 and 4 belonged to B4. In the first four deliveries of Engineering Exploration, most of the design problems were of B1 category, subsequently the difficulty was raised to B2-B4 level. However, B4 level projects are mentor-time intensive and their success largely depends on student-motivation level.

This categorisation of projects is applicable only if standardised parts are being used in building the prototypes. However, the authors opine that, if the design is highly innovative with a large number of customised parts, this categorisation may not be sufficient.

4.2 Relational Complexity

The sample design problems were analysed by representing them as solution graphs. In section 3, the characteristcs of solution graphs are explained. The results of the analysis of design problems with respect to in-degree of a function and the type of control system developed are discussed here.

1. Relational complexity can be seen in terms of number of in-degrees for a process/ function/task in the solution graph for a given design problem. Higher in-degree for a given function (node) means the function has more dependency with the previous functions. Considering the example shown in Figure 1 and Figure 3, the relations for the functions involved in a cup crushing machine are unidirectional and no functions have more than one in-degree. However, for snacks and spice mixing machine, there are multiple functions which execute in parallel. And the function "mix spice and snacks" has an in-degree of 5. Achieving this particular function in the design artefact or prototype becomes complex because of several inputs flowing in. This increases the complexity of snacks and spices mixing machine. It is also to be observed that, the kind of inputs which are flowing into that particular functional block or process also matters.

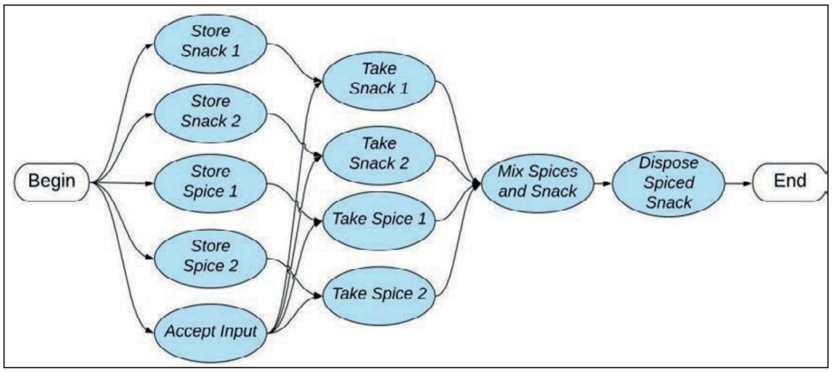

Figure 1: Solution graph snacks and spice mixer design problem

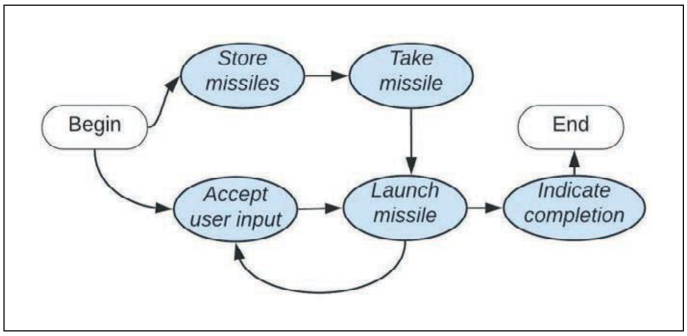

Figure 2: Solution graph for missile launching machine

2. The second dimension of relational complexity lies in the type of control systems developed. An open-loop control system is a kind of system where the output does not affect the actual conditions encountered. The

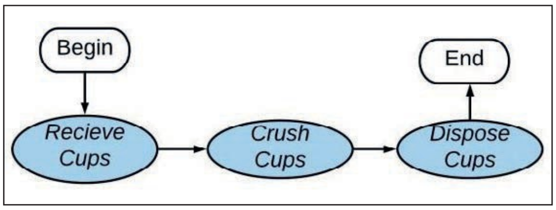

Figure 3: Solution graph for cup crusher design

closed-loop control system has one or more feedback loops that seek to overcome the errors inherent in the system. When compared with closed-loop control systems which are complex, open-loop control systems are simple and inexpensive (Salim & Zainon, 2010). In the context of "Engineering Exploration", the design problems led to the development of open-loop control systems. However, there were certain design problems which were closed-loop control systems, like the missile launching machine (Figure 2) and gaming machine. It is observed that creating prototypes with closed-loop control systems are complex than open-loop control systems.

To summarise, the original definition of relational complexity from Jonassen and Hung (2008) has been analysed using a sample of 21 design problems. Theoretically, relational complexity is dependent on the number of attributes and relations between them. For design problems, relational complexity manifests in the need for feedback and the number of interactions between functions. For the 21 design problems, relational complexity is mostly restricted to functional interactions, with 2 design problems leading to closed-loop control systems.

These set of design problems stem from a first-year engineering interdisciplinary course; many design problems lead to open-loop control systems since closed-loop control systems cannot be given due to limitations on students' technical knowledge and skills. However, in subsequent years, student is expected to build more complex systems which usually will be closed-loop control systems. In such a case, only solution graph may not be sufficient to gauge the complexity, and alternative representations will be needed.

The authors observed that creating design problems which need lower interaction between functions/tasks/processes and whose systems are open-loop control systems are feasible at first-year engineering. For highly interactive systems, the students were unable to identify the interactions itself. This led to an increase in faculty mentoring time.

4.3 Structuredness

According to Jonassen and Hung (2008), structuredness of a problem arises from the number of unknown elements in the problem. Structuredness is characterized by five parameters: intransparency, heterogeneity of interpretations, Interdisciplinarity, dynamicity, and legitimacy of competing alternatives. The same five parameters are used for analysing 21 sample design problems. Although all parameters are applicable for design problems, in the sample considered, only two parameters viz, intransparency and Interdisciplinarity manifested.

Intransparency refers to unknown states of the problem (initial state, goal state, and operators), using which the 21 design problems have been analysed. The results of this analysis are shown in Table 4. An observation of Table 4 reveals that for 12 design problems, only the means/operators were left open for interpretation. In the absence of openness in the other dimensions, the difficulty was only experienced in identifying means. When all the three states were left open for interpretation, the problems were more difficult and this was observed only in 3 design problems.

Table 3: Design problems and degree of ill-structuredness

Design problem	Initial state	Goal state	Means /operators	Observations
Board cleaning machine	Closed	Closed	Open	Diversity in solutions existed in-terms of only cleaning mechanisms, making the problem l.
Missile launcher	Closed	Closed	Open	Diversity existed in-terms of only launching mechanisms
Oscillating toy horse	Closed	Closed	Open	Since the output form was also mentioned, the problem difficulty is less.

A Pet Dog bot	Closed	Closed	Open	Since the output form was also mentioned, the problem difficulty is less.
Classroom cleaner	Closed	Open	Open	Diversity in solutions existed in-terms of functions (sweeping, wet cleaning or dry cleaning) making problems moderately difficult.
Divyang- Solution for the "specially-abled"	Open	Open	Open	Very open, time spent on problem spotting and understanding could not connect to the issue of designing solutions for specially-abled. This has made the problem very difficult.
Musical Robot	Open	Open	Open	Very open, because of which, the solutions had scope for diversity. This has made the problem very difficult.

Jonassen and Hung (2008) have discussed Interdisciplinarity in terms of social, political, economic, environmental (biological), historical, personal implications and many others. However, Interdisciplinarity in the sample design problems was infused through the following course outcome "Identify interdisciplinary approach required in solving an engineering problem". The multidisciplinary team of faculty members identified relevant contexts that demand the application of knowledge and skills from three disciplines: Computer science, Electronics and Mechanical engineering and have crafted the design problems accordingly. Bringing in knowledge and skills of disciplines other than engineering was not a mandate of the course outcomes, hence it is not visible in the design problems as well.

Though Jonassen and Hung (2008) have brought to light five parameters that can contribute to ill-structuredness in design problems, parameters of intransparency and interdisciplinarity played a dominant role in infusing ill-structuredness. The most difficult of the sample design problems, were the ones in which all three states were open for interpretation. As a result, this required more effort during the problem definition phase, thereby increasing the mentor's time and effort. The design problems in which only the means/operators were open for interpretation almost resembled a problem definition. The students were quickly able to proceed to the concept generation phase of the design process which did not lead to the development of outcomes expected from design learning.

For first-year undergraduate engineering design experiences, the authors neither favour the latter type of design problems, as they are intellectually constrictive, nor the former type of design problems, as they overwhelm students. This feeling is due to their prolonged school-level experience of solving well-structured problems. The design problems with openness in both means/operators and goal state provided an optimum design experience when weighed in terms of learning outcomes, mentoring time and effort. Infusing interdisciplinarity in the design problems at first-year engineering is a challenge unless it is the mandate of the course outcomes.

5 Conclusion

Problems are central to learning in PBL courses. Crafting of design problems plays an important part of course design. It requires maturity and consumes lot of efforts from course instructors. The findings from this study evidence that Jonassen and Hung's (2008) framework of problem difficulty, though originally applicable for Problem-Based Learning pedagogy, may be used for crafting design problems for Project-based learning as well. This is demonstrated by analysing 21 design problems that were created for interdisciplinary design experiences at first-year undergraduate engineering. The findings will also guide engineering educators in identifying a-priori the degree of complexity and ill-structuredness in design problems, which is also attainable by students at first-year undergraduate engineering. Since this study is rooted in first-year engineering, it may be difficult to generalise the findings in other contexts. However there is a need for this and it needs further investigation.

Although, Washington Accord mandates the development of twelve graduate attributes (Accord, 2013) around complex engineering problems, the specific operationalisation of complexity across the four-years of an engineering program is a worthy problem to address for engineering educators. The proposed work just touches the tip of this iceberg by demonstrating what complexity and ill structuredness mean in the context of design problems at first-year undergraduate engineering. Further, how the characteristics of complexity and ill-structuredness manifest and interplay for the other category of problems that engineers commonly solve: troubleshooting problems, decision-making problems and system-analysis problems (D. H. Jonassen, 2000) is still an open question.

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Appendix-1

Sl.no	Title	Need Statement description	Academic Year
01	Classroom cleaner	In a classroom, after every class, floor need to be swept and dust needs to be collected. It has been observed that school is facing difficulty in finding labours to do the work. Now, school is interested in automating the sweeping of classroom and ready to invest Rs. 2000/- on automated sweeper system.	2015-2016 (Even semester)
02	Board cleaning machine	There is a necessity of some mechanism of cleaning the board automatically after the teacher winds up the class.	2015-2016 (Even semester)
03	Missile launcher	Army is in need of an automated missile launcher. In a round the launching machine should fire 3 missiles over a span of 3 second and rests for next 3 seconds. (Consider any lightweight objects as missiles, ex: Ping-Pong ball)	2016-2017 (Odd semester)
04	Cup crusher	Municipal Corporation is in need of an automated crushing machine which crushes various paper and board products and throws them in a bin for further packaging.	2016-2017 (Odd semester)
05	Pattern printing machine	There is a need for a machine which cuts the steel sheet in the pattern of alphabets using laser gun. (Assume pen or pencil as laser and paper as steel sheet, where pen or pencil traces the pattern on paper)	2016-2017 (Odd semester)
06	Oscillating toy horse	A Toy manufacturer is interested in launching new product (self-oscillating horse) into the market targeting children with age group of 3-5 years. The toy should bear the load of the kid and should be easy to use. He is keen to have three different variations of oscillations speeds like- 10, 15 and 20 Oscillation/min.	2016-2017 (Even semester)
07	Coloured cube sorting machine	A gift store has wrapped the gifts in red, blue and green coloured wrappers. There is a need for dumping six same coloured gifts into a box and indicate the labour about the accomplishment of the task.	2016-2017 (Even semester)
08	Paper Airplane folding and launching machine	There is a need for a machine which folds an A4 paper into an air plane and launches it. The machine should sense the availability of paper and notify the user after the launch.	2017-2018 (Odd semester)
09	A Pet Dog bot	A toy manufacturing industry in the town is interested in a Pet robot, which can respond to any human act. Sensing can be any human intervention. Industry is insisting that the response of the bot can mimic the actions of a dog. There should be at least 3 different varieties of responses by the bot for different human intervention.	2017-2018 (Odd semester)
10	Carrom bot	There is a robotic carrom competition organized in the university. The competition will be between 2 robots controlled by players.	2017-2018 (Odd semester)
11	Roasted Groundnut skin peeling machine	In a sweet manufacturing industry, there is a need for a machine which can peel off the skin of the roasted ground nuts. Later on those are used for various sweet manufacturing. The machine should be able to detect the availability of the groundnuts and let the user know the completion of the task.	2017-2018 (Odd semester)
12	Six/Eight legged robot	ISRO is planning for another Mars mission. This time they are in need of a robot which can carry a payload and roam around on the mars surface. They are insisting on having a machine which can walk using 6 or 8 legs than wheels for moving around because of odd terrain.	2017-2018 (Odd semester)
13	Robo Soccer	Automation company is advertising a football team by it's robots actually playing a football and they have decided to built a robot which can hit the ball and it is controlled by a player ! The requirements are as follows 1. It should hit the ball at different speeds 2. It should move around the field 3. It should be controlled by the user!	2017-2018 (Odd semester)
14	Wire stripping and cutting machine	Every semester the faculty of CEER has to make kits for Engineering Exploration class, which consists of many components including wires of different lengths. Cutting and stripping wire to required length is fatigue and consumes lot of time. There is a need to automate the process of cutting and stripping of wires	2017-2018 (Even semester)
15	Human arm miming bot	People with lost hand can be supplemented with a prosthetic hand which mimes the motion of the other hand. The prosthetic hand should be able to mime motions of each finger on a hand.	2017-2018 (Even semester)
16	Divyang	People with special needs or Divyangs need assistance for their day-to-day activities like eating, buttoning the shirt, combing, wearing shoes, drinking.Design a way to help such people to carry out their day to day activities without assistance of another person.	2018-2019 (Odd Semester)

17	Musical Robot	For an upcoming event in KLETECH there is need for robot which can play musical instruments to entertain audience.	2018-2019 (Even Semester)
18	Game machine	A new shopping mall which has opened in Hubballi is interested to have an innovative interactive robotic game in their gaming center. Though claw machine was mentioned by the client as an example, she is not very keen on that game machine.	2018-2019 (Even Semester)
19	Automatic Shoe Polishing Machine	A hotel at Hubballi is interested in putting up an automatic shoe polisher as a part of their service to the customers. Unfortunately the existing solutions are quite costly and are asking you to make ready one at lower price.	2018-2019 (Even Semester)
20	Gesture controlled bot	Gesture based robotics is slowly gaining its momentum in industrial applications. A science museum is interested in showcasing this new trend.	2018-2019 (Even Semester)
21	Snacks and Spice mixer	A restaurant serves a variety of snacks on their evening menu. The guests desire different types and level of spices on the snacks. The chef wants an automated solution that can help the guests select the desired type and level of spices for any snack. The snack and spices should be mixed by the machine consistently before serving.	2019-2020 (Odd semester)

Developing Teamwork skills in a multidisciplinary project-oriented course

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Abstract

Literature shows that project-oriented courses that take on the characteristics of Project-Oriented Problem-Based Learning allow students to develop essential skills in the professional life of 21st-century engineers such as teamwork. Since 2018, the Faculty of Engineering of the Universidad de Los Andes has implemented the Multidisciplinary Engineering Design Project (MEDP) course. In the course, students from eight engineering programs create teams of four to five students that are advised by two or three professors from different engineering fields. These teams are invited to select a real context where they will identify problems in order to use their knowledge and engineering skills to propose relevant, viable, multidisciplinary, and sustainable solutions. The first versions of the course showed that the students' previous experiences in teams (multidisciplinary or disciplinary groups) were not favorable in most of the cases. To prevent this fact inevitably leads to blockage of the projects throughout the MEDP course, the teachers design and implemented a pedagogical strategy to develop teamwork skills. Thus, this study explores what are the achievements of implementing the proposed strategy for the course. Using a qualitative approach, information was collected on the course developed in fall 2019 through focus groups, students' written reports, and teamwork assessment rubrics, and they were analyzed by triangulating sources. The analysis shows how the strategy implemented did generate face-to-face communication, emotional management of the team, and anticipation of the outbreak of conflicts in the way of explicit conversations about the discomforts and tensions inside the team, which can hinder and delay the development of the project.

Keywords: Teamwork skills, Project-Oriented courses, multidisciplinary teams, engineering education

Type of contribution: PBL research

1 Introduction

It has been identified that professionals who have the ability to work in teams are highly productive and innovative in their work (Loughry, Ohland & Woerhr, 2014; Strom, & Strom, 2011; McClellan, 2016). Therefore, teamwork is one of the most desired skills employers look for in their candidates (Nowrouzian & Farewell, 2013; McClellan, 2016).

Teamwork is related to so-called soft skills such as adaptability, negotiation, commitment, communication, proactivity, and flexibility. Though these skills are essential for the professional development of individuals as they govern the interaction with other people, few education programs explicitly train students in these aspects (Singer, Guzmán & Donoso, 2009; García et al., 2016) because their development and evaluation are much more complicated than technical or disciplinary skills (hard skills).

This complexity is evident in the fact that there are many proposals to classify, teach, and evaluate teamwork skills. For example, Nowrouzian & Farewell (2013) show that teamwork is a complex competence that demonstrates two types of essential skills those oriented to the task and those of socio-emotional care. The first group is related to the skills of finding relevant information to develop the proposed task and execute the expected products; the second ones are related to the maintenance of communication, support, and stimulation among the team members throughout the ability to handle conflicts.

From the other side, Strom and Strom (2011) use a different classification to develop an instrument (The Teamwork Skills Inventory) to evaluate teamwork. This tool relies on peer and self-evaluation to establish accountability, identify competencies, and detect learning needs concerning five skills: 1) attends to teamwork, 2) seeks and shares information, 3) communicates with teammates, 4) thinks critically and creatively, and 5) gets along with teammates. This information allows guiding the effort of teachers and students in the development of these skills in specific courses.

Another approach corresponds to implementing curricula that favor the development of teamwork skills, as Project Oriented - Problem Based Learning (PO-PBL) curriculums. At the University of Aalborg, this curriculum model organizes students in interdisciplinary teams to address the projects, while offering students relevant courses to strengthen the development of projects technically, scientifically and socially (Dahms et al., 2017; Hernández et al., 2016; Kolmos et al., 2004; Ravn, 2008). A usual strategy in project courses is establishing a team contract where students propose a form of self-organization that allows them to carry out the project (Kolmos et al., 2008).

Additionally, in the Faculty of Engineering and Sciences of this University, students pursue a *Problem-based learning course in Science, Technology and Society (PS)* during their first semester. The purpose of this course is for students to understand the university's curriculum model and to develop skills to learn collaboratively, concerning the socio-environmental consequences of technological solutions to engineering problems (Dahms et al., 2017). This course includes specific activities that allow students to reflect on their experience in the projects, as well as acquiring tools to analyze the organization of teamwork to identify strengths and weaknesses, which will enable them to propose improvements in similar future scenarios. Additionally, these courses highlight the need to generate explicit pedagogical strategies for the development of teamwork.

2 Context

Since 2018, the Faculty of Engineering of the Universidad de Los Andes has implemented the Multidisciplinary Engineering Design Project (MEDP) course. In the course, students from eight engineering programs create teams of four to five students and are advised by two or three professors from different engineering fields. These teams choose a context for them to identify problems and use their knowledge and engineering skills to propose relevant, viable, multidisciplinary, and sustainable solutions.

This course emerges as an initiative from the dean's office to promote multidisciplinary work and more direct interaction of students with organizations and contexts outside the university. The curricular approach of the course follows the educational PO-PBL principles: 1) The problem is the starting point directing the student's learning process, 2) project organization creates the framework of problem-based learning, 3) the students are responsible for their own learning achievements, and 4) the problem-based project work of the groups must be exemplary (Dahms et al., 2017; Hernández et al., 2016; Kolmos et al., 2004). This course is elective to all the students of the last three semesters of any of the faculty programs.

According to the results of surveys and focus groups, the first versions of the course showed that the students' previous experiences in teams (multidisciplinary or disciplinary groups) were not favorable. In most cases, the usual strategy of students to work as a team was to divide the project inform requirements, to realize them individually and finally put them together in a single document, delivered within the proposed time frame, without further interaction between team members.

The most common problems of this strategy were, on the one hand, the cases where some student did not contribute to the project but was included as part of the team, and on the other hand, the very controlling students who did not allow others to contribute to work, or modified joint agreements or delivered alone without taking into account the contributions of others. As a consequence of these experiences, many students preferred to work alone or with peers they already knew very well and with whom they had no conflicts.

This fact inevitably led to blockage of the projects throughout the MEDP course, mainly because most of the students did not know each other and had no references on how their classmates worked in teams, worsening the feeling of distrust. Considering that the project course is not accompanied by other courses where these teamwork topics could be worked explicitly as Aalborg PO-PBL model and that the students needed a strategy to develop teamwork skills, the teachers decided to generate a pedagogical strategy embedded in the development of the project itself.

The learning model of the course takes up Wenger's (2001) proposal on social learning, the negotiation of meaning, and the construction of communities of practice through participation (actively interacting and creating identity in the community) and reification (transforming abstract information into real artifacts). That is compatible with the learning cycle of Kolb (1984), where learning starts from the student's specific experiences but requires three other actions to complete it: observing, thinking, and planning (Figure 1).

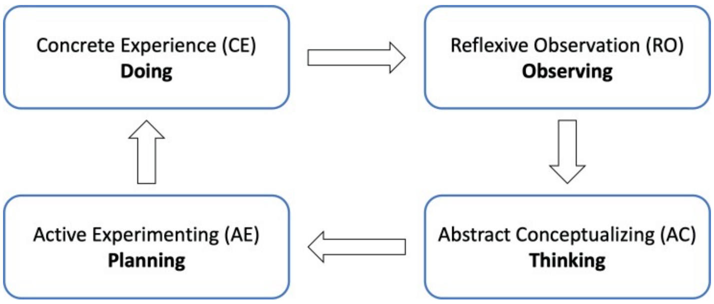

Figure 1: The learning cycle of Kolb (1984)

The development of the project in the course consists of four phases, each one spanning four weeks: Structuration, Ideation, Prototyping, and Implementation. The teams must present an oral and written report of the development of the project to close each phase. The final grade has two parts: the products of each phase account for 85%, and the remaining 15% is for the teamwork skills. The students assign this 15% themselves, through mechanisms of auto and co-evaluation.

Nowrouzian and Farewell's approach (2013) shows that it is essential for good teamwork to help the students to review and reinforce their own skills oriented to the socio-emotional management of the team and its members. For this reason, the pedagogical strategy in MEDP was generating an explicit learning cycle for teamwork skills in each phase (Figure 2). The first class of each phase begins with activities aimed at reflective observation on the concrete experience of teamwork to make the lived processes evident. Additionally, workshops and discussion of reading material are held where students conceptualize teamwork concepts. Finally, the teams plan how to test the model or theory in forthcoming experiences. For example, in the first class, the contexts are presented, and the multidisciplinary teams are formed. Students in groups do an exchange of positive and negative experiences on teamwork, reflect on these experiences, and develop the team contract, including self-regulation rules that allow them to have a positive experience in the course.

Then for four weeks, students´ experience is their active participation in the processes carried out in the class, and they are focused on the task and execute the expected products (reification). In addition to the delivery of these disciplinary products, the teams are asked to carry out some evaluation activities about their teamwork to close the phase. In the next session class, a new phase begins, and a new learning cycle is developed. Thus, at the beginning of the ideation, prototyping, and implementation phases, the students' reflection is carried out using the previous cycle's experience, the results of their disciplinary products, and the different activities to conceptualize teamwork. Finally, they are invited to review and adjust the team contract according to the identified needs and achievements.

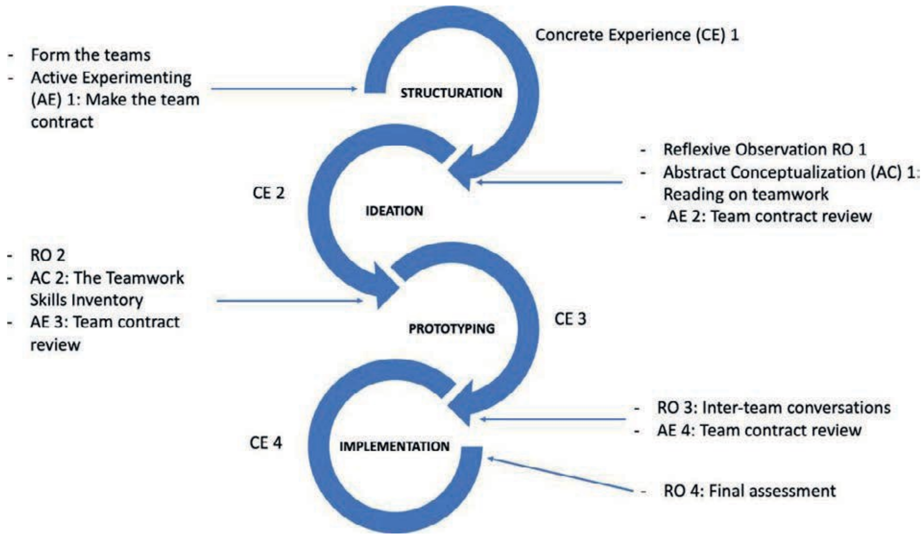

Figure 2: The pedagogical strategy in MEDP. Students live an explicit learning cycle for teamwork skills in each project phase.

At the end of the implementation phase, each student using a matrix designed by teachers individually carried out a qualitative and quantitative assessment of their team's work during the development of the project. Next, all the group members discussed the assessment carried out and agreed on a final grade justifying in writing the reasons for this evaluation.

This strategy was implemented in the fall of 20190; there were 30 students from different engineering programs: environmental (7), chemical (2), mechanical (2), biomedical (5), electrical (3), civil (2), systems and computing (7), electronic (1) and industrial (1). They conformed six multidisciplinary work teams and adopted one different real context each. A group of ten teachers, also from different engineering fields, accompanied the teams. The research question that arises is, what are the achievements of implementing the proposed strategy for the course?

3 Methodology

This study was developed with a qualitative approach and from a critical and hermeneutical perspective. This perspective allows the researcher to understand a phenomenon from the generality and from the detail, which makes it possible to strengthen a valid and pertinent discourse against the reality of the subject studied (Alvesson & Skoldberg, 2009). In particular, this inquiry seeks to identify the learning results observed in the MEPD courses developed in fall 2019, when professors implemented the pedagogical strategy described before.

In the first session of the course, the researchers familiarized students and teachers with the development of this study, and they authorized the collection of information and subsequent analysis through the signing of informed consent. The anonymity of the participants is also taken care of throughout the document.

The researchers collected information in each phase or learning cycle of the course through focus groups, students' written reports, and teamwork assessment rubrics. These are different sources that provide different type of data about three topics relative to teamwork: students' experience, the use of the tools proposed by the teachers, and the learning achieved. They analyzed results by triangulation of sources to characterize the process of developing teamwork skills in students and identifying the learned skills. Finally, relevant fragments were translated from Spanish to produce an English narrative.

4 Results

This section is organized following the evolution of the students' teamwork abilities through the development of each project phase.

4.1 First learning cycle: Structuration

At the beginning of the course, it was relevant to know the students' expectations against the knowledge they expected to learn and the skills they hoped to develop. In general, the interests of students focus on learning and applying engineering knowledge. Since the students who take this course are close to graduation, they understand this course as a bet to expand their experience, learning, and training as engineers:

> “It is like trying to characterize real and existing problems and looking for a solution that can mitigate the problem or eradicate it, and then assess the impact of that solution” (Initial student’s focal group)

> "I think [multidisciplinarity] quite diversifies teamwork, as it helps to integrate better all points of view to tackle a specific job. Also, you start to generate other links, meet more people, and see other points of view, not only academic but also personal." (Initial student’s focal group)

These responses show that at this stage, it does not seem that teamwork skills development is a proposed objective in the course, but rather one of the inherent characteristics to carry out the task.

Although the students did not identify some difficulties or tensions that may arise when working as a team initially, the teachers of the course considered the elaboration of a teamwork contract in this phase as a specific strategy to support the teams in the development of teamwork skills. In this regard, students expressed as follows:

> “The making of the contract generated dialogues and built the team's commitments on the base of the needs and concerns that each member considered important. Therefore, it contains all the agreements to carry out activities as well as basic rules, such as punctuality.” (Intermediate student’s focal group)

4.2 Second learning cycle: Ideation

In the second phase, the students' reflections on the multidisciplinary dimension of the course as a central element were more mature, and challenges and strategies become clearer as students delve into the development of the project:

> "Multidisciplinary involves twofold work: you have to learn things from the project but also from working with others. We have a project that is not specific to any of our engineering fields, and we have had to learn from scratch. That has also united us a lot. We agreed that each one explains to the others what they have found, and then we have no frictions." (Student’s written ideation report)

These reflections emerge from the explicit expectations of students related to the exercise of engineering in multidisciplinary teams and demonstrate the task orientation that characterizes their previous experiences. In this sense, the students reported challenges related to the different work rhythms characteristic of their disciplinary training:

> "Each engineering has its work rhythm. I do a double program, and I see it a lot in my two engineering fields. Each one has a different rhythm of work that collides when not all of us are in the same way." (Student’s written ideation report)

Similarly, task orientation is reflected in student references to differences in study methods for each team member:

> "Regardless of the program, there are people who have different study methods. Some people think they can get done everything at the last minute, and that's fine, but not everything can be left until the last minute. This course is not about respecting study methods or that working under pressure works for you. We are working with a real-life company that requires progress constantly." (Intermediate student's focal group)

In this phase, students do auto-evaluation and co-evaluation using Teamwork Skills Inventory. With each team's results, teachers generate a graph on five dimensions of teamwork, allowing them to visualize their performance, dialogue face to face about these results, and, thus, anticipate possible attitudes and behaviors that hinder the development of the project. **¡Error! No se encuentra el origen de la referencia.** shows an example of the results of a team in which members rarely seek and share relevant information for the development of the project. The exercise ends with a new revision of the contract that includes small commitments from each member to improve the quality of teamwork.

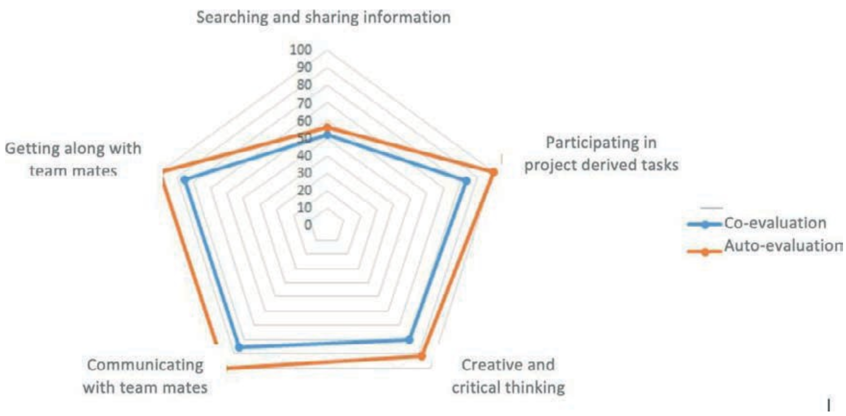

Figure 3. A graphic example of teamwork self-assessment` results in The Teamwork Skills Inventory. The teams use this information for reflection and review team contract.

During the focus group, the students reported having safe spaces to provide mutual feedback, which led to reflections on small actions that can negatively affect the team's work environment:

> "The important thing about the co-evaluation is that each one sees what has to change. If 30% of the team thinks that you did arrive on time and 70% say no, one says: next time I have to arrive early. Therefore, each one can see what bothers others. That forces you to think more about what you do." (Intermediate student's focal group)

4.3 Third learning cycle: Prototyping

In this phase, the students were invited to share their experiences with groups other than their own. In the focus group the response on this activity was unanimous

> "We took advantage of the fact that we do not share so much between teams in the course sessions, and we assume that *what happens in Vegas stays in Vegas,* and we shared what happened in each team without prejudice. It was positive to see that many of the problems we have are similar and that we were able to learn from other teams that had managed to overcome similar situations." (Final student's focus group)

This extract evidences of greater openness and willingness of students to speak and share about their experiences of teamwork as an essential element to take into account for the development of projects.

Subsequently, they were asked to review their teamwork contract agreements to create a habit of reviewing, updating, and renewing work agreements. The teams developed work strategies autonomously and organically, according to their characteristics and interests:

> "In the first review of the contract we agree a rule: for non-attendance at team meetings, the fine was to buy pizza and beer; it is basically that. We wanted to integrate the group beyond an academic bond, a friendlier one to contribute to the group's relationship develop properly." (Final student's focus group)

> "In my team, the work dynamics that we have built are based on talking among ourselves. We have come a long way in talking, saying what is working, what is not, what we do, and not just reviewing the contract; maybe we have not done that a lot." (Final student's focus group)

4.4 Fourth and least learning cycle: implementation

The evaluation matrix used in the final exercise included the following criteria: emotional management, clarity of objectives, distribution of responsibilities, detection and resolution of problems, and planning. The results presented below correspond to group justifications for the level of performance assigned.

4.4.1. Emotional management. Five of the six teams reported a high level in this criterion based on the fact that there are concrete actions that demonstrate the collective awareness of caring for emotional management as a critical element of teamwork:

> "We create spaces outside of class to share and relate beyond the project. It was also very important to always be able to communicate better. Initially, we defined a work rhythm that was adjusted to everyone's personal needs and styles. We realized that respect was essential and helped us build trust and honesty, which favored supporting us, saying difficult things without offending us, and participating in other non-academic spaces that greatly enriched us." (assessment report team 2)

The sixth team reported an intermediate level and argued that:

> "It is not that we do not take care of the emotions but that, in general, there are not many. We get along, but we do not talk beyond the project because we do not believe that it is necessary." (assessment report team 5)

4.4.2. Clarity of objectives. This criterion refers to the action strategies and the awareness of these by all team members with no difficulties in establishing priorities. The teams argued:

> "This was the most relevant aspect for the success of our project because having a clear strategy allowed us to continue moving forward and meet the objectives, we had set for ourselves." (assessment report team 2)

> "In the middle of the semester, we realized that we had to find a strategy to improve our results because we were not being productive. We found software that helped us plan and record the tasks, so we managed to orient ourselves to the proposed objectives." (assessment report team 6)

The team who self-assigned an average score wrote:

> "It was not always easy to have clear objectives. They changed throughout the project, and we did not realize that it was not trivial to define priorities, so an important advance for us was to reach a point of mutual agreement on those objectives." (assessment report team 5)

4.4.3. Distribution of responsibilities. In this criterion, the teams that reported high performance argued the use of various strategies:

> The software made us stop arguing because there it is clear what everyone does. We assigned ourselves very specific roles and that helped a lot to be always focused on what we should do. If someone could not do something, the person just had to ask for help, and that worked very well for us. (assessment report team 6)

The team that reported an insufficient level argued:

> "Many times, people in the group ignored the activities, leaving those undone because nobody knew who the job was for, or we didn't realize it wasn't assigned, and then it wasn't done." (assessment report team 3)

4.4.4. Detection and resolution of problems. The four teams that reported high performance on this dimension had a positive view of the problems:

> "We realized that the entire project would be full of unforeseen situations and problems, so we agreed not to discuss but to have the most assertive communication possible, accept mistakes, apologize and think among all how we could consciously improve." (assessment report team 4)

> "We decided to carry out a conscious review of each phase to identify delays, strengths and inconveniences that could affect us in the future, and thus we sought to anticipate. So, when a problem arose, we were more proactive." (assessment report team 2)

The satisfactory level teams argued:

> "We were all aware of the problems, but some ignored them or thought about how to solve them. It was not difficult to identify general and individual problems, but sometimes we could not assume a group vision to solve them." (assessment report team 5)

4.4.5. Planning. All teams reported a high level of planning, with plans to meet the objectives and a task schedule for the members. Given this, they argued:

> "We had a schedule. The problems many times were not from our planning but from the company, that always delayed us a lot, making it look like we did not plan." (assessment report team 5)

> "Using the software helped us a lot to change this because it was difficult in the first phase, and we did not manage time well. We also set up a weekly planning-only meeting; it was a great idea." (assessment report team 6)

These fragments evidence how the proposed criteria allowed the teams to evaluate reflectively different aspects of their performance as a team. The diverse reasons for a team to assign itself an assessment correspond to the particular characteristics of these small communities throughout the semester.

Finally, in the individual reflections that are part of the final document each team has to deliver, we asked students to tell us about their valuable learnings from the course. We present the following extracts, where some students manifested their experiences on teamwork and showed their learnings:

> "It was very important for me to understand that group communication problems will always be the biggest obstacle to the development of a group project. They do not allow progress and generate discord among the members. It is even more important to generate empathy and good relationships within groups, even more than the same work that is developed individually." (Student's written final report)

> "Thanks to the multidisciplinary approach, I discovered that each branch of engineering has something very valuable that can provide a solution to almost any real-life problem. The course also helped me improve my way of working in a team, accepting different points of view, and recognizing when my contributions were not entirely correct." (Student's written final report)

"Teamwork was key, and we all managed to coordinate to be successful in prototyping. After each supervision or presentation, we always met to discuss the quality of our work and how we could improve. There was one time in particular when we did not perform as expected in the presentation, and we began to blame ourselves. However, we reflected on it and decided to focus our time and energy on finding solutions and not guilt. We managed to speak directly, assertively and concisely among ourselves as partners. Thanks to all this, we managed to carry out a project that, at first glance, seemed lost." (Student's written final report)

5 Discussion

The results of the course's implementation show that the first achievement is to make students aware of the importance of developing teamwork skills. In particular, at the beginning of the course, students can take these activities lightly given their orientation to the task and that they consider having a functional prototype to be the most important as reported by Singer, Guzmán & Donoso (2009) and García, et al., (2016). However, the final reflections show how students identify that these skills are central to being able to perform well in the development of the project.

A second achievement is that at the end of the course, a significant number of teams report developing high levels of the two types of skills raised by Nowrouzian & Farewell (2013): those oriented to the task and those of socio-emotional care. The arguments raised by the teams allow us to identify that these skills are developed simultaneously, for example, establishing respectful communication allows teams to more quickly identify the problems in the project and be more proactive in proposing solutions.

A third achievement is to generate in the teams a dynamic of reflection and dialogue. Each team can be seen as a small community of practice in which students actively participate to develop affiliation and purpose, for example, by establishing their own rules through the contract. Although from the design of the strategy, the permanent review of these contracts presupposes helping the teams to reification their participation, the results show that in few opportunities the students carry out this process as systematically as the teachers expect and, on the contrary, create emergent structures that respond to their characteristics, identities, and interest as proposed by Wenger (2001). However, the strategy of having specific times to observe and reflect on their experience using detailed information about their performance, the health of their team, their emotional management, the experiences of others, and reading material about teamwork encourages students to generate face-to-face conversations about complex issues that can lead to conflicts in the community. This safe environment promoted genuine and purposeful communication that allowed them to assume everyday challenges in the development of projects collectively.

The last achievement is to reinforce to professors that the design and implementation of the explicit strategy for the development of teamwork skills are necessary because students have not necessarily previously learned how to work as a team. However, by articulating the team skills learning cycle to the development of the project itself, the educational principles of the PO-PBL are preserved, and it generates a different use of the course's time and pedagogical resources. Similarly, to the case presented by Dahms et al. (2017) at Aalborg University, at MEDP, one of the teachers' necessary actions is to promote and support students in these reflective processes. The great challenge for professors is to promote reflections without striving to make students rigorously follow the rules of self-organization. Thus, the professors align with the principle of the students being responsible for their own learning achievements. In this way, the teachers allow teams to develop their own strategies and assume the consequences that derive from them.

6 Conclusions

Developing competencies such as teamwork within a project-oriented course requires a clear pedagogical strategy towards this goal. The analysis of the results observed in the MEDP course shows how the strategy implemented did generate teamwork skills as face-to-face communication, emotional management of the team, and anticipation of the outbreak of conflicts in the way of explicit conversations about the discomforts and tensions inside the team, which can hinder and delay the development of theproject.

The fundamental characteristic of the presented strategy is that it integrates with the development of the project phases. Thereby, it favors the reflection of the students and generates exemplarity in the experience of teamwork. As a consequence, it promotes concrete learning that students can use in future experiences. The challenge remains for professors to assume their role as a facilitator of the reflectiveprocess.

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Active learning in a large, lecture-based course: Hands On Wednesdays in an introductory engineering course

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Abstract

This paper describes the redesign of Introduction to Statics, often the first technical engineering course introduced in a US engineering curriculum. Traditionally a large, lecture-based course, the redesign was prompted by instructor dissatisfaction with students' foundational skills in following courses. Based on the institution's commitment to project-based learning, the course was restructured into a hybrid model of lectures and active learning modules called Hands On Wednesdays. The impact of Hands On Wednesday was examined in Fall 2019 with 55 students in one Statics class using the Student Assessment of their Learning Gains. Multiple regression models isolated the contribution of Hands On Wednesdays after controlling for student background and the extent to which students found attending lecture useful. Having a high quality Hands On Wednesday experience had a significant positive effect on several learning outcomes (eg, learning how to defend a proposed solution; learning how to draw appropriate free body diagrams) and student attitudes (eg, confidence in understanding the material; comfort working with complex ideas), and no relationship to others (eg, identifying the type of problem). Additional faculty are implementing the model and their assessment will further isolate areas for improvement.

Keywords: curriculum redesign, STEM, large student groups, hands on, active learning

Type of contribution: PBL practice

1 Introduction

The rapidly changing global workplace demands complex problem-solving skills – and undergraduate STEM education has been widely called upon to adapt to help students prepare for this evolving post-baccalaureate landscape (NAE, 2004, 2005; NAS, 2007; Nielson, 2011; NRC, 2012; PCAST, 2012). While college educators aim to equip students with the foundational knowledge and technical skills of specific disciplines, students also need to develop transferrable skills in order to be successful (Robertson, 2018). According to Hart Research Associates (2018), potential employers of graduates prioritize skills that cut across majors, such as analytic reasoning, complex problem solving, and applying knowledge to real-world settings.

These skills can be developed alongside content knowledge and skills through well-designed learning environments and intentional active learning pedagogy. When students actively engage in learning experiences, they learn to work things out for themselves, have confidence in their own analytical abilities, make connections to the world, and determine how to harness their innate curiosity to discover the power of their own learning abilities (Doyle, 2008). This exploratory study was motivated by practitioner self-study and subsequent course redesign to include a new set of active learning modules, called Hands on Wednesdays. Three research questions guided the design and analysis:

1. To what extent does Hands on Wednesday improve students' learning of content, engineering skills, and skills for active learning?
2. To what extent does Hands on Wednesday improve students' metacognitive learning?
3. To what extent does Hands on Wednesday improve students' engineering self-efficacy?

2 Literature Review

The redesign of the course fits within the broader context of what we know about how active learning works and its impact on students, particularly in undergraduate STEM education.

2.1 Active Learning

Active learning has been broadly implemented and widely claimed in response to calls to improve undergraduate STEM education (Hart Research Associates, 2016; Wurdinger & Allison, 2017). In the context of this paper, we consider active learning to be any style of instructional methodology in which students are engaged in the learning process (Prince, 2004). This is a broad definition following the wide variety of strategies, tools, and activities that are considered under the trend of "active learning."

Yet not all instructional methods described as active learning yield the same level of impact on student learning and transferrable skill development. Chi and Wylie (2014) expand upon binary active learning/traditional lecturing conceptualizations to more finely assess the quality of teaching and learning. Their ICAP framework posits that instructional activities involving interactive behaviors among learners yield the best learning results, followed by constructive, active, and passive learning behaviors, respectively. The hands-on activities detailed in this paper primarily incorporate interactive and constructive behaviors, whereas the lecture sessions involve both active and passive behaviors.

Freeman and colleagues (2014) conducted a meta-analysis of 225 studies and concluded that undergraduate students were 1.5 times more likely to fail STEM courses taught with traditional lecturing than were students enrolled in classes taught with active learning. Student performance on equivalent measures of learning gains (eg, examinations, concept inventories) was 0.47 standard deviations higher in active learning classes than in those with traditional lecturing. According to well-established links, we would expect students who participate in active learning components of courses to experience learning gains in content and skills.

2.2 Metacognition

At their best, active learning strategies not only teach students new knowledge and skills, but also strengthen students' ability to engage in their own learning. We hypothesize that active learning can increase students' metacognition, which involves the cognitive mechanisms students use to know and to regulate their own knowledge (Herscovitz et al., 2012; Vos & De Graaff, 2004; Vrugt & Oort, 2008). Metacognitive processes allow students to use strategies to approach a task, monitor and evaluate their progress, and adjust their approach when needed (Shank, 2017).

To develop into independent, lifelong learners who are capable of being successful in today's workforce, individuals need to know the general learning strategies available to them and their varying purposes. Students who have acquired a set of general learning strategies are more likely to apply them to studying and in tackling different classroom tasks, thus enabling students to learn more and perform better (Pintrich, 2002). By defining and applying performance criteria and building in opportunities for students to receive and use feedback, students can develop their metacognitive skills (Doyle, 2008). Engagement in activities that include the kinds of demands coupled with the dynamic conditions of real-world settings can help learners assess their skills and identify where improvement is needed (Brown, Roediger, & McDaniel, 2014). These metacognitive skills are a critical component of active learning in engineering education (De Graaff & Christensen, 2004; Wengrowicz, Dori, & Dori, 2018).

2.3 Self-Efficacy and Persistence

The nature and quality of classroom instruction plays a significant role in student decisions to persist in their college education (Braxton, Hirschy, & McClendon, 2004). The higher self-confidence a student possesses, the greater the chance that the student will engage in a task and succeed (Cummings & Connelly, 2016). Cummings and Connelly (2016) found that repeatedly using simulation activities in an active learning environment with nursing students increased the student confidence levels. We hypothesize that repeated hands-on activities will boost student confidence and lead to increased self-efficacy.

Freeman and colleagues (2014) also showed that failure rates decrease significantly in active learning STEM classes compared to traditional lecture classes. These increased success rates provides students with the ability to persist in their education. Increased passing rates and higher student engagement level leads to better student retention in the STEM majors (Watkins & Mazur, 2013). Active learning, such as the strategies outlined in our study, helps students to build their content skills while developing self-confidence needed to fuel their persistence through the course of their educational journey.

3 Course Redesign

This study assesses student learning gains for a pilot of a course, Introduction to Statics, which was redesigned from a traditional lecture mode to include weekly active learning modules. The course is a gateway to multiple engineering degrees and is often taught in large sections.

3.1 Motivation for Redesigning Introduction to Statics

As students develop into engineers, they learn skills that build upon prior knowledge, both personal and technical. Students who make connections between their personal passions and the engineering field are more likely to remain engaged in their engineering education (Deters & Leydens, 2017), particularly for underrepresented minority students (Denofrio, Russell, Lopatto, & Lu, 2007; Lent, Lopez, Sheu, & Lopez, 2011). These connections are easily observed in project work when a student who cares deeply about assistive devices has the chance to design a prosthetic or a student who has always loved space has the chance to analyze rocket design. By personally relating to the topic, students may make deeper and more meaningful connections to the technical content.

Making personal connections to foundational technical content can be more difficult to excite in students. The instructor for the class described in this paper has taught second year mechanical systems courses for the past five years. The redesign was informed by two observations made during that time. The first critical observation was that students complete and often excel at one course in isolation without being prepared to apply that content to future courses. In a Mechanics of Materials course following Introduction to Statics, students often struggle to draw correct free body diagrams for complex systems utilized for the next steps in mechanical design and analysis. The second critical observation was that higher level students often have difficulty estimating and evaluating the appropriate solutions to their design challenges. A student might do a thorough and detailed technical design of a hand operated device that required a user to apply 1,000 lbs to operate without realizing that this final value was not realistic. This disconnect between the hand calculations and the physical world leaves students less prepared to make meaningful connections between their technical content and the world around them.

At the root of the course redesign was a question: could this disconnect between a physical relationship with the physics students were analyzing be related to their inability to make connections between technical content learned across the curriculum? Hands On Wednesdays were designed to give students opportunities to observe and feel the phenomena they were learning to solve on paper and therefore develop a physical intuition about the world around them. Learning and applying technical skills is an iterative process; Hands On Wednesdays allow students to practice identifying and applying the governing fundamental processes and equations to both simple and complex problems. Using a kinesthetic approach might excite students about content that is traditionally dry and abstracted from the exciting engineering applications that drew them to the field. If students could get excited about learning the fundamentals in engineering courses, they may make stronger connections to the content and be better prepared to identify the need for, and apply those fundamental skills.

3.2 Hands On Wednesday Design

The Introduction to Statics course is an ideal intervention point as it is one of the earliest core courses that mechanical engineering students will experience. Hands On Wednesday as developed and integrated using a staged approach. A hands-on session was incorporated into each week of the 7-week term to give students regular hands-on interactions with challenge levels that progressively increase over the term. In early sessions, students interact with replicas of their homework problems. This gives them the chance to develop an intuition for the sizes and loads that they are using in paper based systems. In these early sessions, students have the chance to make basic physical skills connections that are often overlooked on paper. For example, identifying an origin within a physical system in order to define vectors is essential both on paper and in the physical world; however, coordinates and locations are generally predefined in paper based problems, and as such, deep thought is not required during traditional problem sets. Student groups see the importance of defining an origin at the Cube in Space station. At this station they are given a 2x2x2 foot PVC cube to measure the magnitudes of several position vectors. To measure these magnitudes they first need to identify the vector end points in space relative to an origin. Once they realize the need for an origin, and identify this point, students use string and tape to mark position vector end points in space, allowing them to measure the vector magnitudes. Defining physical attributes like these in real space at Hands On Wednesday stations activates a different set of problem-solving operations.

As the term progresses, Hands On Wednesday sessions incorporate more complex twists on homework problems, eventually progressing to challenges that students see for the first time in their hands-on sessions. In each session, students are asked to think beyond the technical calculations to further develop their physical intuition. As the difficulty in activities increases, students are asked questions to prompt reflection, such as identifying minimums and maximums they see in a system, locating balance points, and ascertaining experimental error.

4 Methods

This study uses a mixed methods approach with concurrent quantitative and qualitative measures. This paper reports the first phase of the study with a single course section of students in the first term of the 2019-2020 academic year.

4.1 Sample

All students (n=90) enrolled in a single section of Introduction to Statics were invited to participate in the study. Of these, 63% (n=57) chose to participate. The sample comprises 60% underrepresented minority students with one or more of the following identities: women, non-binary gender, Black, Latinx); members of these identity groups are underrepresented in STEM in the US (NCES, 2015).

4.2 Methods and Data Collection

Data were collected using the Student Assessment of their Learning Gains (SALG; Carroll, Seymour, & Weston, 2000), which was originally constructed as a means of shifting student assessment of courses away from evaluating professors to instead report self-assessments of their learning. The SALG has been used by more than 21,000 instructors to assess half a million students across the US in projects funded by the National Science Foundation under the Research Experiences for Undergraduates opportunity (salgsite.net).

We use four scales from the SALG to measure gains in content and skills learning, active learning, metacognitive learning, and self-efficacy. Factor structure and scale validation were confirmed and are reported in a separate paper. Individual items ask students the extent to which they made gains in various specific aspects of their learning using a five-point Likert scale from “no gains” to “great gains.” Scale scores were calculated by deriving the mean for responses to items within the scale. Examples of items from each scale are provided in Table 1.

The survey asked students for their race/ethnicity, gender, and academic effort in high school. The survey item about academic effort asked students to complete the stem “My experience of the work required in high school classes was:” with one of four possible responses: “It was very easy for me to get the grade I wanted in all my classes,” “With a few exceptions, it was easy for me to get the grade I wanted in my classes,” “I had to work some, but not all that hard to get the grade I wanted in my classes,” “I had to work hard to get the grade I wanted in my classes.” The influence of attending lectures on student learning was assessed with a question asking “How much did each of the following aspects of this Statics class help your learning?” with a five-point Likert scale from “No Help” to “Great Help.” The same question stem asked students to report the influence of Hands On Wednesdays. The SALG was administered at the end of the statics course via online survey. Responses were anonymous.

Table 1. Examples of Items from SALG Scales of Student Learning and Self-Efficacy

Content and Skills Learning Scale	Active Learning Scale	Metacognitive Learning Scale	Self-Efficacy Scale
The main concepts explored in this class	Working effectively with others	The mental stretch required by tests	Confidence that you can do statics work
Identifying what type of problem you are asked to solve	Participating in discussions during class	Explanation given by the instructor of how to learn or study the materials	Confidence that you understand the material
Developing a logical argument to defend a proposed solution	Willingness of seek help from others when working on academic problems	The way the grading system helped me understand what I needed to work on	Your comfort level in working with complex ideas

4.3 Analysis

Data were first assessed for bivariate correlational relationships at the item and scale score levels. Sufficient significant relationships were found to warrant further examination using multiple regression. A set of hierarchical linear regressions were calculated to predict the four learning outcomes (gains in content and skills learning, active learning, metacognitive learning, and self-efficacy). The first model included student background using two variables – URM status and high school academic effort. The second model controlled for student background variables and added the effect of attending lectures. The third model controlled for student background and attending lectures variables and added the effect of Hands On Wednesdays.

5 Findings

Hands On Wednesday had a significant positive effect on several learning outcomes and student attitudes after controlling for student background and the effects of attending lecture.

5.1 Active Learning

Experiencing high quality Hands On Wednesdays significantly predicts gains in active learning, even after controlling for student background and the effects of attending lectures, with F(4, 52) = 17.10, $p < .001$. The four predictor variables explain 57% of the variability of active learning gains. The effect of Hands On Wednesdays has approximately the same effect on active learning gains as the effect of attending lectures (see Table 2).

Table 2. Predictors of Gains in Active Learning

	Model 1			Model 2			Model 3		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
URMStatus	-.07	.23	-.04	-.10	.18	-.06	-.05	.15	-.03
HSEffort	-.13	.11	-.16	-.04	.09	-.06	.00	.07	.00
AttendingLectures				.51	.09	.60*	.37	.08	.44*
HandsOnWed							.38	.08	.47*
R^2		.03			.38			.57	
F for change in R^2		.87			29.32*			23.09*	

*$p < .01$

5.2 Content and Skills Learning

After controlling for student background and the effects of attending lectures, experiencing high quality Hands On Wednesdays significantly predicts content and skills learning, with F(4, 52) = 10.91, $p < .001$. Together, these predictor variables explain 46% of the variability of contents and skills learning gains. While the effect of attending lectures is larger than the effect of Hands On Wednesdays (see Table 3), the effect of Hands On Wednesdays contributes an additional 10% of explanatory power, significantly improving model fit with F(1, 52) = 9.48, $p < .01$.

Table 3. Predictors of Gains in Content and Skills Learning

	Model 1			Model 2			Model 3		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
URMStatus	-.16	.19	-.81	-.18	.16	-.12	-.15	.15	-.10
HSEffort	-.11	.09	-.17	-.05	.08	-.07	-.02	.07	-.03
AttendingLectures				.41	.08	.56*	.33	.08	.45*
HandsOnWed							.23	.08	.34*
R^2		.05			.36			.46	
F for change in R^2		1.38			25.46*			9.48*	

*$p < .01$

5.3 Metacognitive Learning

After controlling for student background and the effects of attending lectures, Hands On Wednesdays has a significant effect on metacognitive learning gains, with F(4, 52) = 17.69, $p < .001$ (see Table 4). These predictors explain 58% of the variability of metacognitive learning, 12% of which is contributed by Hands On Wednesday alone – a significant improvement on model fit, with F(1, 52) = 14.03, $p <.001$.

Table 4. Predictors of Gains in Metacognitive Learning

	Model 1			Model 2			Model 3		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
URMStatus	.24	.25	.13	.21	.19	.11	.25	.17	.13
HSEffort	-.10	.12	-.12	.00	.09	.00	.04	.08	.05
AttendingLectures				.64	.10	.67*	.52	.09	.55*
HandsOnWed							.33	.09	.37*
R^2		.03			.46			.58	
F for change in R^2		.70			43.04*			14.03*	

*$p < .01$

5.4 Self-Efficacy

In addition to assessing the effects of Hands On Wednesdays on student learning gains, we also calculated the same set of hierarchical linear regressions to examine the effect on students' self-efficacy. After controlling for student background and the effects of attending lectures, Hands On Wednesdays has a significant effect on gains in self-efficacy, with F(4, 52) = 8.34, $p < .01$ (see Table 5). Together, these four variables explain 41% of the variability of self-efficacy. As with gains in student learning, gains in self-efficacy explain a significant amount of variability: 9%, with F(1, 52) = 8.34, $p < .01$ for change in R^2.

Table 5. Predictors of Gains in Self-Efficacy

	Model 1			Model 2			Model 3		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
URMStatus	-.27	.25	-.15	-.30	.21	-.17	-.27	.20	-.15
HSEffort	.07	.12	.08	.15	.10	.18	.19	.09	.22
AttendingLectures				.52	.11	.55*	.41	.11	.44*
HandsOnWed							.29	.10	.33*
R^2		.02			.32			.41	
F for change in R^2		.68			22.88*			8.34*	

*$p < .01$

6 Discussion

The extent to which students found Hands On Wednesdays to contribute to their learning correlates highly with the extent to which students report gains in active learning. This is expected, as Hands On Wednesdays are designed specifically to engage students in active learning. These findings suggest that Hands On Wednesdays are responsible for a significant portion of the learning gains students attributed to active learning in this course. More specifically, Hands On Wednesdays had a significant effect on two aspects of student learning that active learning is frequently called upon to address: students' self-efficacy as engineers and their metacognitive awareness of their own learning. However, perhaps the most pressing finding of this pilot study is the effect of Hands On Wednesdays on content and skills learning. For those worried that active learning strategies such as these might benefit "soft skills" at the loss of content learning, this study provides counter-evidence.

In order to build upon the findings detailed in this paper, data collection should be expanded to include students in other sections of the Intro to Statics course that are implementing the Hands On Wednesdays activities. This broader set of data will help to validate the current findings for each of the identified factors, as well as allow for more depth analysis to determine the relationships between these factors. Most studies on active learning have been primarily focused on the effectiveness of the techniques on students' academic achievement, such as those included in the metaanalysis performed by Freeman and colleagues (2014). However, some basic connections have been hypothesized that increase in student performance in active learning courses is responsible for student retention in STEM majors (Freeman et al., 2014; Watkins & Mazur, 2013). Through the use of the SALG, we will be able to explore these connections in more depth to better define the relationships between academic performance and the development of important transferrable "soft skills" such as metacognition and self-efficacy.

By controlling for the students' perceptions of the lecture experience, we were able to isolate the effects of Hands On Wednesdays specifically. Hands On Wednesdays would be classified as Interactive based on Chi and Wylie's (2014) ICAP model. There is still a gap in the literature for evaluating the effectiveness of specific active learning techniques on student learning. While Chi and Wylie (2014) hypothesize that Interactive experiences yield the best learning in comparison to Collaborative, Active, and Passive experiences, this current study could be expanded to help validate the ICAP model through differentiating the experiences students are having within the lecture portion of the class as compared to Hands On Wednesdays.

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A PBL-environment for Smart Buildings

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Abstract

This paper presents findings from a PBL-project developed for Civil Engineering students in their 4th-year of studies being enrolled in an elective module entitled "Software Systems". The PBL-scenario is based on a comprehensive problem description being developed and valid for a whole academic year. The problem given to the students is to design, install, run, and maintain a building automation system for one floor of a building hosting offices, labs, class-rooms, storage facilities of our own institute, i.e. the students use "their" facilities as a "living laboratory". Even if the design and implementation of software systems is considered to be an engineering discipline, it is perceived as a field of interdisciplinary studies, since knowledge from computer science and domain-specific engineering expertise from other engineering disciplines are amalgamated to form the overall body of knowledge.

Thus, civil engineering students taking this elective must acquire a substantial amount of new knowledge and expertise from computer science and develop "learning trajectories" into the different domains of Civil Engineering. For the design of a good building automation and control system, knowledge about the building topology, building physics and building services systems design complements the expertise in automation systems.

The above challenges for teaching and learning are well covered by the characteristics of PBL, such as: (1) Learning is motivated by open-ended problems, (2) Problems are context specific, (3) Students actively investigate and solve problems, preferably through collaborative work (4) Students identify the key problems and agree on solutions, (5) Knowledge is acquired through self-directed learning, (6) Academic staff adopt the role as mentor, promote a learning culture of inquiry and assist students through guidance rather than direct instruction. To summarize: PBL motivates students to deploy knowledge in new situations, i.e. students are exposed to ill-structured problems and are expected to propose alternative solutions.

Keywords: problem-based learning, engineering education, Smart Buildings, civil engineering

Type of contribution: PBL best practice

1 Introduction

The paradigm of Smart Buildings is frequently referenced in our daily life. Smart buildings are expected to consume resources in an optimal way and to pollute the environment in a minimal way. However, the design of smart (sub-)systems which are supposed to work in an integrated way and expected to deliver smartness holistically requires the knowledge and expertise from multiple disciplines. The integrated design and automated management of monitoring and control systems for building components is one major aspect of delivering "smartness".

Given the above, educators of architectural and engineering students are exposed to an enormous challenge, i.e. to deal with increasing complexity in education. The authors argue that the availability of a "Living Laboratory" has a great potential to support an interdisciplinary teaching and learning process, since students can experience the effects of their actions immediately, or in other words students benefit or suffer from the results of their own project work.

2 Framework for the PBL-scenario

The PBL-scenario described in this section is part of a module entitled "Software Systeme" (engl. Software Systems) covering 8 ECTS and running over two terms in the 4th year of a five-year degree programme in Civil Engineering at Technische Universität Dresden, Germany. The material covered in the winter term is delivered under the heading of "Systementwicklung" (engl. Systems Design) whereas the Summer term is delivered under the heading "Systemintegration" (engl. Systems Integration).

2.1 Goals

The purpose of the module is to impart knowledge about the analysis, design, implementation, testing, and maintenance of software systems. The example use case is the area of building automation and control (BAC). In the first term, students are provided with an opportunity to acquire the theoretical foundation of software engineering. For this purpose, we use a textbook written by Bernd Bruegge and Alain Dutoit (Brügge & Dutoit, 2013). Since we are working in a multi-lingual environment, it is helpful that both German and English editions exist for the textbook. The project task for the first term is the preparation of three documents, such as (1) a Requirements Analysis Document (RAD), (2) a Systems Design Document (SDD) and (3) an Object Design Document (ODD).

Based on these specifications students work on the system's implementation, testing, and documentation in the 2nd term (Summer term). The final goal of the project is, to have the installation of a BAC-system completed, well documented and handed over to the client after the two terms.

In addition, students should learn to work in groups and to distribute tasks according to the abilities of the individual participants. The use of the PBL methodology aims to ensure that students not only have the theoretical knowledge of how software systems are developed, but also have already practiced these concepts on an application example. Additionally, students are expected to learn that BAC-software interacts with building components. Only if this interaction functions as expected the whole system of a building delivers the full value of engineering activities to the building owner and tenants.

2.2 Participants

In the current academic year, the module is taken by 5 full-time and 2 part-time students. Seminars are prepared and supervised by two research assistants. Tutorials are delivered by students from higher semesters who had already taken the module in previous years and were able to contribute to the project through their constructive advice and feedback.

3 Problem-based learning

In contrast to direct instruction, Problem Based Learning (PBL) is designed to impart specialist knowledge and soft skills by motivating students to internalize the content of the course more effectively (Kolmos, 2017). Instead of focusing on a detailed, predetermined teaching content, everything revolves around the learner, who can follow the path of knowledge acquisition tailored to their own needs. The starting point is knowledge previously acquired. By means of a practice-relevant task, those working on the topic are supposed to deal with a self-diagnosed problem, to analyse it and to search for possible solutions.

The aim is to immediately reveal where knowledge gaps exist. By clarifying the initial conditions, requirements, objectives and basic terms of the project, it is expected that learners close these gaps incrementally. Usually, specialists from different areas relevant to the problem are partly involved in the supervision. Thus, group work is an additional enabler to close knowledge deficits more efficiently. Should problems remain unsolved, it is still possible to fall back on independent research at the end. The building blocks of Problem-based Learning are explained in the following subsections.

PROCEDURE: The acquisition of knowledge in PBL is an iterative process. In every run, the problem is the starting point. To solve it, the current state of knowledge is first determined. Based on this knowledge, it is now possible to identify missing knowledge and to correct it in the subsequent knowledge acquisition phase using the learning resources. Based on this, a proposal for a solution can be presented. All phases are accompanied by group discussions, which serve to evaluate the results and advise on the next steps (Zumbach, 2003). Tutors that lead their students in small groups guide the entire process.

PROBLEM: The problem determines what knowledge is required and how realistically the defined problem is related to practice. Ideally, a problem common to the professional field should be chosen. Usually, academic staff constructs the problem. The use of media (e.g. videos, documents and pictures), the inspection of problem locations, or the use of problem-related objects are well suited to assist students in understanding the problem specification.

TUTORS: should have a broad basic knowledge and extensive expertise of the problem domain, as they (1) create the problem, and (2) guide the individuals or groups in finding a solution. Further tasks are: (3) Assistance in case of emergency, (4) Control and guidance through the solution process, (5) Evaluation of individual performance and teamwork.

Supporting activities in the context of teamwork include, for example, conducting group discussions. This enables teams to steer the discourse back in the right direction in an emergency. The tutor controls the process of finding solutions by asking for specific content and organising learning materials (Mills & Treagust, 2003). Through the close involvement in the group meetings, individual assessment of students is better possible.

LEARNING GROUP: The size of the learning group impacts the quality of structured knowledge acquisition in a team. Group sizes of four to nine learners are recommended. Smaller groups reduce the amount of prior knowledge entered, whereas larger groups make close cooperation more difficult (Yewa & Goh, 2016). In order to maintain the team spirit, the groups stay together for a longer period of time. If gaps in knowledge occur, it is advisable to choose the person with the greatest interest to acquire additional knowledge. This ensures a sufficient quality and depth of the new knowledge. The designated group member presents their findings to the group following and based on the self-research.

LEARNING RESSOURCES: It is important that learners are free to find and use their own individual and most appropriate learning path. Therefore, different ways of acquiring knowledge shall be supported by offering different learning resources. Examples are: lectures, workshops and discussion groups with people from industry.

4 Methods

Following a careful selection process, it was decided to use the textbook "Object-Oriented Software Development with UML, Design Patterns and Java" (Brügge & Dutoit, 2013) as the textbook for our PBL-course. Reasons for selection were amongst others: (i) the structure of the book can be easily adapted to PBL-scenarios, (ii) the book is available in English and German Editions (Brügge & Dutoit, 2013), (Brügge & Dutoit, 2004). Figure 1 illustrates how major software engineering activities recommended by Bruegge et al. could be mapped to major PBL-features. On this basis we explain our approach to PBL in the next sections in more detail.

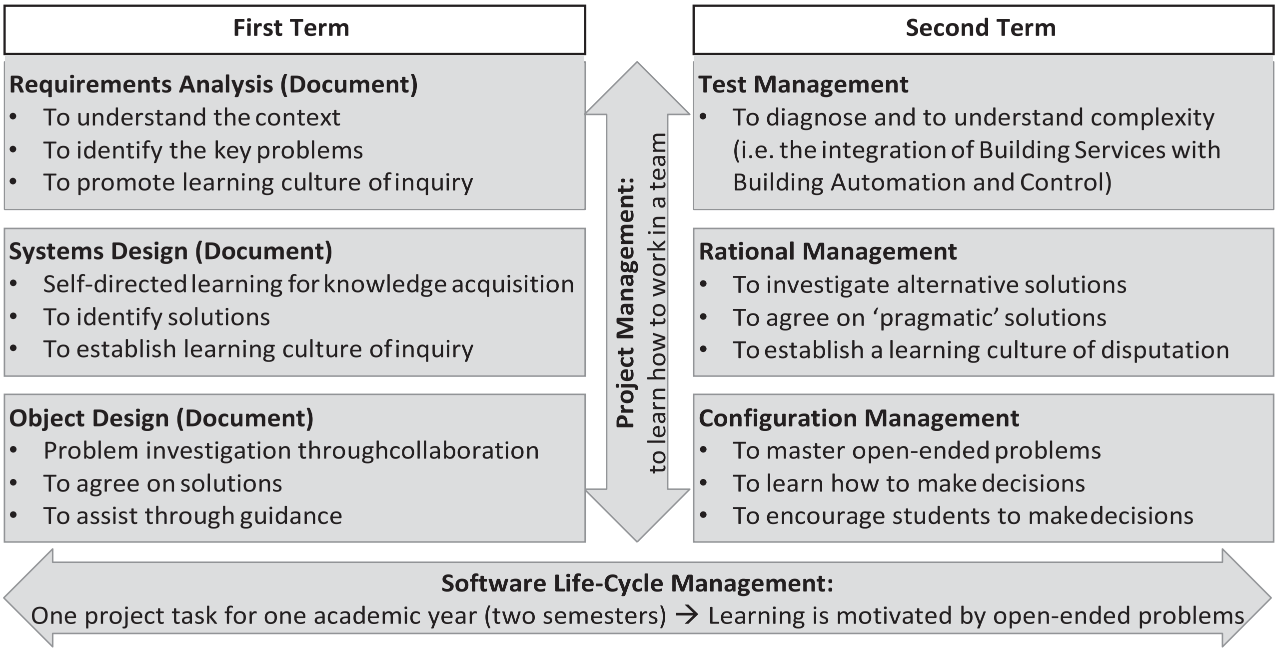

Figure 1: Mapping Software Engineering Activities to PBL-features

4.1 Requirements Elicitation and Analysis

Requirements Elicitation is, according to Bruegge et al., one of the initial steps of the Software Engineering Life Cycle. It is used to investigate with the client the problem domain, i.e. the area in which a software should be used. In our PBL-scenario we have chosen the area of "Delivering Human Comfort in Buildings".

The selection of the topic shall illustrate that Human Comfort in buildings is achieved through the integrated usage of (1) Building Elements (e.g. thermal mass, shading effects) designed by Civil Engineers and Architects, (2) Buildings Services Systems (e.g. HVAC, Lighting) designed by Mechanical and Electrical Engineers, and (3) Building Automation and Control Systems designed by Computer Scientists and Electrical Engineers. To understand the above context on the basis of standardised digital models is one major task for the students in this early project phase (Menzel, et al., 2013).

In comparison, Requirements Analysis starts to "translate" the domain specific requirements into an IT-specific framework. Part of this PBL-activity is to enable the students to identify "key problems". Examples are: What are single comfort elements and how are these controlled, e.g. Thermal Comfort is usually controlled by other means than visual comfort. However, solar gains might be considered as desirable for visual comfort but as negative impact for thermal comfort (overheating) during the Summer season.

From an instructor's point of view, it is important to prepare the students for the PBL-scenario and to raise their awareness for new forms of teaching and learning to be practised in the subsequent steps, i.e. to promote a learning culture of inquiry. The result of this step is the RAD (Requirements Analysis Document).

4.2 System Design

According to Bruegge et al. one major step in System Design is the definition of Design Goals. This includes a prioritisation or weighting of design goals, since some design goals may contradict each other. Up to their 4th-year of study the students had limited exposure to multi-criteria evaluation and decision scenarios. Therefore, the need to identify holistic, integrated solutions is new to the student participants. A second major software engineering activity is system decomposition. This activity enables academic staff to establish a learning culture of inquiry, since through decomposition knowledge deficits in the non-civil engineering disciplines become quickly transparent but can be addressed in a targeted way.

The result of this step is the SDD (Systems Design Document).

4.3 Object Design

In Software Engineering the focus of this phase is on interface design and on the reusability of design solutions. Interface design is a classical collaboration problem. Thus, student participants are now motivated to foster the interaction between teams but also individuals in teams. Furthermore, the challenge to make an initial design solution more generically applicable also requires collaboration, since the impacts of generalisation must be discussed across teams.

In this phase, academic staff acts as an observer and has an opportunity to make contributions to the disputation process of the student-participants and thus guide or influence the outcome of the discussion process. The result of this step is the ODD (Object Design Document).

4.4 Test Management

In this phase it is planned how to synthesize individual development and implementation results. The authors argue that this might be the most challenging phase for the PBL-scenario, since the building automation components are integrated with building elements or building services components. In order to diagnose the functionality of a system as a whole, students must have understood the complete system. A trivial example for test management is the question "Why does the radiator remain cold?". There are many reasons: (a) The result of the student project might be dysfunctional, i.e. the actuator is wrongly programmed. (b) The radiator valve is dysfunctional, i.e. a mechanical part. This is not part of the building automation scenario but it must be addressed. (c) The boiler, heat exchanger, etc. is dysfunctional. Again, this is out of scope of the PBL project. The result of this step is the TMD (Test Management Document).

4.5 Rational Management

In this part students are expected to document design alternatives, those initially chosen and those not selected for implementation. However, since our student project runs over multiple seasons, students may have to come back to another solution, since the design goals may change. A simple example for this case is the operation of windows. In the beginning of the project, during the Autumn and Winter period the driving force for the window operation is the air-quality (usually determined by the CO2-Level). However, in Spring and Summer it might be desirable to additionally run a scenario which supports overnight cooling. In this case windows are supposed to be opened in the early morning, the coldest time of the day. The result of this step is the RMD (Rational Management Document).

4.6 Configuration Management

In PBL-scenarios all participants – learners and teachers – are exposed to a learning curve. Students may discover in their project new software tools, simulation engines, etc. Thus, all team members are exposed to open-ended problem. Therefore, the scenario also contains elements in which participants must decide if a change, replacement, etc. is in the best interest of the overall project result; if this change is 'affordable' and if the overall completion of the project can still be achieved with manageable risk. The result of this step is the CMD (Configuration Management Document).

5 Implementation: Problem and Learning Path

MILESTONE 1: In term 1, phase 1 students prepare a Requirements Analysis Document (RAD). Requirements must be elicited by students from the client (i.e. staff of the institute). The RAD should contain functional and non-functional requirements of software systems. In a first step possible use case scenarios are to be defined and presented. The RAD must be written in a generally understandable way. No expert knowledge should be required on the client's side to understand the content. The RAD is written in close cooperation with the tenants (i.e. employees of the institute). The requirements for the system are derived from real use cases of rooms (e.g. south facing library, north facing visualisation lab).

MILESTONE 2: Based on the RAD, a System Design Document (SDD) is to be prepared. The purpose of the SDD is to define specifications of the system that are relevant for software developers. The proposed system is to be broken down into its individual hardware and software components. Additionally, students must define access control and the global control flow.

MILESTONE 3: The Object Design Document defines the classes and interfaces of the software to be developed- Additionally, the interfaces between control unit, database, and user interface are of particular relevance. Milestone 3 completes the first term.

MILESTONE 4: Term 2 starts with the preparation of a Test Plan. This document specifies testing scenarios for system components by incrementally increasing the complexity of integration. For this purpose, the individual test contents and steps are planned.

MILETONE 5: This phase focuses on the implementation of the software system including the documentation of the source code.

MILESTONE 6: If available, change requests of the customers (Institute for Building Informatics) shall be implemented. A final report and a Lessons Learned Document will be prepared by the students.

5.1 The Living Laboratory

The Living Lab is based on the 3rd floor of a seven-storey office building in Dresden, Germany. The overall usable floor area is approximately 300 sqm (see Figure 2). Four rooms shall be equipped with automation technology, including (1) The Library and Seminar room (201), (2) the Archive and Video-conferencing Lab (204), (3) The Laboratory for Digital Construction (210), and (4) The Laboratory for Digital Design (213A).

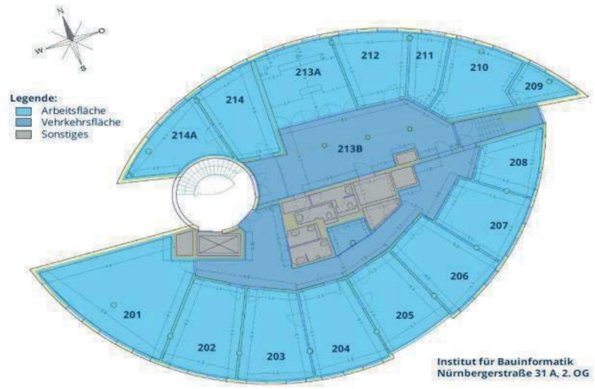

Figure 2: Floorplan 3rd floor

Figure 3: Sample of Sensors and Actuators

A total of 24 sensors, 19 Actuators, and 5 Network components were made available to students (see Figure 3). Sensors include (1.a) a weather station, (1.b) 8 temperature sensors, (1.c) 4 thermal comfort sensors (T, RH, CO2), (1.d) 7 Visual Comfort Sensors (Presence, lux-level), (1.e) 2 Magnetic Sensors, (1.f) 2 Electricity sub-meters. Actuators include: (2.a) Thermostat-Drives for radiators, (2.b) 3 Window-Actuators, (2.c) 3 wireless switches (on/off) and (2.d) 3 wireless switches (on/off/change).

6 Initial Results

Since this paper reports about a current PBL-scenario, running over the Academic Year 2019/2020, final results can only be presented at the conference. However, it is worthwhile to present and discuss intermediate findings on the basis of students' achievements after the first term in February 2020.

A major challenge for students was the exposure to the Living Laboratory scenario, i.e. being told that at the end of the academic year a running software solution is expected. This meant, students were also made responsible to plan, execute, and test the installation of BAC-components. This was a major additional motivation for self-directed learning. For example, students had to develop a test scenario, to verify that the BAC-radiator integration works as a complete system. Students quickly learned from exploring the haptic set-up that the analysis of the temperature measured at the radiators' thermostat did not contribute to the verification. Thus, students had to install two additional sensors to the radiators, to measure the "supply" (top right) and the "return" temperature (lower left) at each radiator (see Figure 4). Only by correlating the room temperature, the temperature on the valve, the supply and return temperature one can prove that the overall heating system is fully operational (Menzel, et al., 2014)

Figure 4: Measurement points at radiators

Figure 5 below depicts one initial BAC-system's dashboard enabling students to use the developed system for diagnosis tasks, since (i) the external and internal temperature (first row), (ii) the supply temperatures (second row) and (iii) the valve temperatures and set-points (third row) can be correlated to each other.

External: Temperature Room: Relative Humidity, Temper.
Supply Temperature (per radiator valve)
Automated Thermostat • Temperature (large) • Set-point temperature (small figure)

Figure 5: Initial screenshot from the BAC-system's monitoring dashboard

7 Evaluation Criteria

For the evaluation of the students' performance we are using four groups of Key Performance Indicators. Each KPI is broken down in further Performance Indicators (PI). Each PI is linked to a dedicated student achievement, either documents (RAD, SSD, ODD, TMD, RMD, CMD – see chapter 4) or oral contributions, such as FP (final presentations), followed by D (disputations). Each element is graded, i.e. a performance indicator is determined. The performance indicators are weighted as shown in Table 1.

Table 1: (Key)Performance Indicators and their weighting for students' evaluation

Evaluation Criterion	PBL-PHASES and EVALUATION 1	2	3	4	5	6	weighting
A) KNOWLEDGE ACQUISITION							0.25
Core Knowledge			FP-1				.1
Knowledge fr. other disciplines			D-1			FP-2	.075
B) SIMPLE PROBLEM SOLUTION							0.24
Key Problem Definition	RAD						.08
Identified Solutions		SDD					.08
Agreed Solution			ODD				.08
C) SYSTEMIC PROBLEM SOLUTION							0.39
Planned Synthesis				TMD			.13
Alternative Solution					RMD		.13
Documented Decision Process						CMD	.13
D) TEAMWORK							0.12
Teamwork Skills			FP-1			D-2	.06

8 Initial feedback from students

In order to set-up a structured approach to record student experience we decided to use a framework published by Choy et al. (Choy & Lim, 2012) since our own student cohort is of limited size and thus a stistically valid identification of problems and themes is impossible. Furthermore, we used for the evaluation of the student feedback qualitative rather than quantitative specifications following the Likert Scale, such as: (🡅) strongly agree, (🡥) agree, (🡆) neutral, (🡦) disagree, (🡇) strongly disagree. In the following sections we briefly discuss the student feedback.

8.1 A new way of studying

Even if the course is still ongoing, intermediate feedback from students can be presented. This was compiled in focus groups, one organised at the end of the first term in February 2020 and the second one organised at the end of Phase 4, i.e. during the second term whilst completing this paper.

Currently, PBL-scenarios are not the common way of lecturing at TU Dresden. Thus, students need to adjust to new challenges and learn how to use the available new degrees of freedom. In order to analyse PBL as a new way of studying we asked students for their feedback in three categories: (1) Learning process, (2) PBL-structure, and (3) Work with problem statement. Table 2 (overleaf) summarizes the findings.

Learning Process: While students appreciated the PBL-scenario in general, they felt like they are given too much freedom with the assignment. Especially in the beginning of the academic year students had to adjust to self-directed and independent learning. Students also expressed that there are deficits on research skills, i.e. how to acquire and evaluate newly acquired knowledge.

PBL Structure: According to the students' feedback it seems that motivation, time management and discipline are not a big challenge to students. This may relate to the fact that students in the 4th year of a degree programme learned how to manage their life in an academic institution.

Work with Problem Statement: Since our PBL-scenario is part of an elective module, motivation is not highlighted by students as problematic. In comparison students find it difficult to synthesize their findings. Corresponding to this seems to be the fact that students find it more difficult to work with the problem statement in phases when detailed practical work is required and towards the end of the project.

Table 2: Initial feedback from students (part 1)

What did you find problematic	*Phase 1: RAD*	*Phase 2: SDD*	*Phase 3: ODD*	*Phase 4: TMD*
Learning process:				
Use of self-directed learning	↗	→	↘	↘
Independent learning	↗	↗	→	↘
Dearth of research skills	↗	↗	→	↘
How to use available resources	→	↗	↗	↘
PBL-structure				
Lack of (self)motivation	↘	↘	↘	↓
Lack of time to complete tasks	→	↗	↑	↗
Lack of discipline	↘	↘	→	↗
Requirement to produce a document for each phase	→	→	↘	↓
Work with problem statement:				
Inability to understand the problem statement	→	→	↗	↗
Unmotivated by problem statement	↓	↓	↗	→
Inability to synthesize findings	↗	↗	↑	→

8.2 The complementing acquisition of soft skills

In order to analyse how PBL as a new way of studying may contribute to the development of additional soft-skills, we asked students for their feedback in additional two categories: (1) Team oriented approach and (2) Presentations.

Team Oriented Approach: This part was perceived as a substantial challenge, since so far the distribution of work, i.e. the allocation of tasks to students, was executed by academic staff. Students expressed difficulties in how to judge if a task allocation is perceived by peers as fair. In comparison, well performing students regretted that they could not work exclusively on the development of innovative solutions. In some cases, this was perceived as a lost opportunity. Finally, in the beginning of the project the negotiation of solutions amongst peers was perceived as problematic. Students had to learn to speak out and to deal with critique in a progressive manner. The need to deliver in time was not perceived as challenge.

Presentations: This part seems to be less critical and was not perceived as a substantial challenge. According to the feedback, students felt confident to present, to take questions in/or after presentations and felt capable to ensure the quality of presentations. Table 3 summarizes the results.

Table 3: Initial feedback from students (part 2)

What did you find problematic	*Phase 1: RAD*	*Phase 2: SDD*	*Phase 3: ODD*	*Phase 4: TMD*
Team-oriented approach:				
The need to demonstrate leadership	↑	↗	→	↘
The need to negotiate ideas	↗	↗	→	↘
The need to delegate work to peers	↑	↗	→	↘
The need to deliver in time	↘	↘	↘	↓
Presentations:				
Lack of confidence in giving presentations	↘	↘	↘	↓
Fear of questioning during/after presentations	→	→	↘	↘
Difficulties in ensuring quality of presentations	→	↗	→	↘

9 Summary

From the perspective of the Chair and its academic staff numerous positive effects are noticed, such as:

(1) A higher number of participants remained enrolled in the elective module. The number of enrolled participants increased substantially compared to previous years.

(2) The motivation of the participating students increased, documented by timely submission of documents, intensive revision or work on iterations and more hours spent in the University's facilities, i.e. the Living Lab.

(3) An increasing number of requests how to make the "LivingLab" more "liveable", e.g. to purchase comfortable chairs, install spaces for work with own laptops, team areas, etc. These are challenges we are happy to take.

So far the installation of a "LivingLab" to support problem based learning resulted in various positive reactions. The establishment of the Lab was a pre-requisite to propose an inter-university, cross-disciplinary "pilot course" which will be jointly organised with HTWK in Leipzig. Whilst completing the final version of this paper we received approval for 18 months of funding under the Digital Fellowship Programme of the local government in Saxony, entitled "Complex Problem Solving Strategies for Engineers using Virtual Reality and Big Data".

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From the business model to business processes design and technological support: a project-based learning approach

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Abstract

This paper focuses on the drivers, curriculum and Project-Based Learning (PBL) learning strategies applied to the Business Process Modelling course, part of the Master in Services Engineering and Management (MESG), while presenting critical reflections on said course. The curriculum unit aims to develop skills that we consider essential in the analysis, design, management and improvement of processes that support the services provided by an organisation to its customers.

Since the creation of the course, the main objective has been to motivate students to look into exploratory approaches to address specific challenges. In this sense, the PBL approaches explored have proved to be quite successful. Students are organised into larger teams and asked to come up with an innovative business idea. Then, they ought to carry out a project focused on the analysis and design of the business processes of the organisation/company, as well as specifying the respective supporting technological elements. The project, carried out as a team, is of medium/high complexity and long duration (throughout the semester). Each team is encouraged to use appropriate digital tools to support the collaborative work, namely, to facilitate information sharing, activity coordination, documentation management and communication.

In this paper, we focus on the implementation and evaluation of the PBL practice, as well as on the analysis and consideration of the lecturers and students' experience. We've adopted a cooperative and student-centred teaching and learning strategy since the beginning, in order to provide the right conditions to put into effect the skills of "doing" and "learning", without neglecting “knowledge”. Accordingly, we point out the main challenges, the lessons learned and the future views regarding the PBL practice.

Keywords: Curriculum design, PBL implementation, teamwork, bpm, services engineering

Type of contribution: PBL best-practice

1 Introduction

The importance of the service sector in developed economies led to the development of a new area integrating relevant knowledge: Service Science, Management and Engineering (SSME). SSME is a term introduced by IBM to describe service science, an interdisciplinary approach to the study, design, and implementation of complex service systems, in which specific arrangements of people and technologies take action to provide value for others (Maglio & Spohrer, 2008)(Vargo, Maglio, & Akaka, 2008)(Spohrer, Maglio, Bailey, & Gruhl, 2007). In this sense, new courses are currently being created to help students develop multidisciplinary skills to design, implement and operate service delivery systems - which, nowadays, are increasingly based on technology. Furthermore, it is now consensual that engineering training should, in addition to technical skills, promote the development of a set of outlooks (related to permanent learning and that of a change agent) and the acquisition of competences (such as creativity, communication, decision making and citizenship) that enable the students' integration in organisations, so they achieve professional success.

It is important to mention that organisations/companies (in the industry and service sector) are gradually adopting organisational practices and the management of work activities, i.e. process-oriented, in order to ensure and increase effectiveness and efficiency. In this context, the orientation towards business processes, namely process management, seems to be differentiating. However, and despite the already mature implementation of quality management and improvement systems in various types of organisations/businesses, there are several gaps and problems at the level of analysis, modelling, management and improvement of business processes.

The Business Process Modelling curricular unit, a key-element in the Master in Services Engineering and Management, proposes a set of contents that help students developing skills that allow them to identify, analyse, model, document, manage and improve service-oriented business processes, while framing them in the business models of the organisations and their strategic objectives. The Project-Based Learning (PBL) methodology has been used since the creation of the course, in order to address the analysis and design of services supported by information technologies. The primary objective of the course is to motivate students to look into exploratory approaches in the context of service-oriented design, grounded on systems engineering techniques and tools, to address specific and multidisciplinary challenges. This led to the adoption of a cooperative and student-centred teaching and learning strategy, in order to provide the right conditions to put into effect the skills of "doing" and "learning", without neglecting “knowledge”. In this sense, the PBL approaches explored have proved to be quite successful.

In what concerns the possible strategies considered in the integration of PBL in the curriculum, we would say that our option fits in the so-called integration strategy, since it is very much oriented towards the inclusion of skills and projects into the syllabuses of existing courses - particularly company projects that most often require a cross-disciplinary approach (Kolmos, 2017).

The students are organised into larger teams to carry out a medium/high complexity project throughout the semester. From the collaborative generation of innovative service-oriented business ideas, to the analysis and design of the business model (and related business processes), and the specification of the respective supporting management platform, each team is encouraged to use appropriate digital tools to support said collaborative work, which facilitate information sharing, activity coordination, documentation management and communication.

This paper aims to present the strategy followed, focusing on the implementation and evaluation of the PBL practice, as well as on the analysis and consideration of the lecturers and students’ experience.

2 The Master in Services Engineering and Management

The Faculty of Engineering of the University of Porto (FEUP) became a precursor in this field, thanks to the creation of the Master's Degree in Services Engineering and Management (MESG), in September 2007. Accordingly, MESG seeks to leverage the technology-based skills previously developed by students, complementing them with multidisciplinary skills in the area of services design and management. In this context, MESG students will be specifically prepared to, on the one hand, bridge the gap between the customer, the business and the management of services, and, on the other hand, develop and manage the technology-based systems that support them.

2.1 The need for multidisciplinary competences

The traditional services, provided from person to person in a physical location, have been evolving into a system of services provision through multiple channels (physical stores, Internet, telephone, interactive kiosks, etc.), with technology playing a crucial role -, whether the services are provided by a person or by self-service solutions. Since technology is the core of many services today, they ought to be designed and managed in an integrated manner.

MESG shares the general principles of the FEUP scientific and cultural educational mission. Concerning the specific objectives, MESG aims to provide students with a 3-year degree in engineering sciences, technologies or related fields, helping them develop skills for the design, implementation and operation of technology-based service systems. The MESG (duration of two academic years – 120 ECTS) comprehends the development of skills in 'T' (T-shape), complementing the First-Degree training of students (vertical component of 'T') with a set of multidisciplinary skills in the area of Engineering and Services Management (horizontal component of 'T').

This Master relies on an Engineering approach with distinctive aspects, namely when compared to other Master's degrees in services. Said approach comprehends the following aspects:

- Systems approach, crucial for dealing with service systems that integrate people, processes and technologies, (e.g. healthcare services);
- Process design and management, vital for services that are fundamentally a coherent set, linked by a flow of work activities;
- Information and Communication Technology (ICT) skills development, crucial to deal with the importance and massive use of technology-based services;
- Strong Conceive, Design, Implementation and Operation (CDIO) approach to service systems, with a strong focus on technology-based services.

Being a Master, MESG often includes a multidisciplinary set of students, the vast majority coming from Engineering and Economics/Management. The study plan contributes to a clearer selection of optional curricular units for students with a background in Engineering/Science or Economics/Management. In this sense, students with a background in Engineering can choose a set of optional units that reinforce their management skills, while students with a background in Management can choose a set of optional curricular units that improve their skills in engineering.

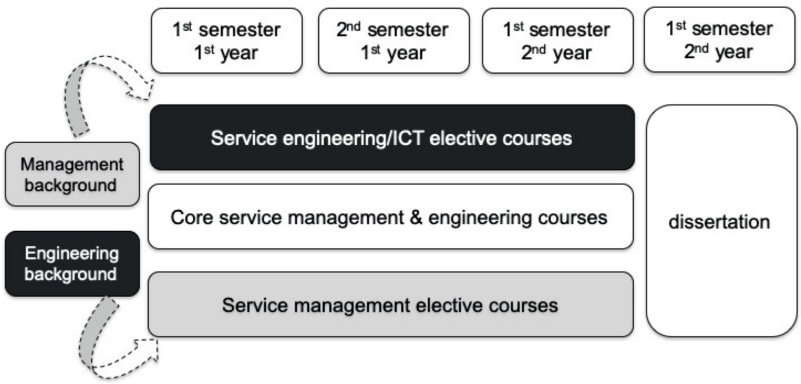

Figure 1: MESG study plan

2.2 The BPM curricular unit

The Business Process Modelling (BPM) takes place during the 1st semester of the 1st year of the MESG, being one of the six core curricular units - within the scientific field of engineering. BMP corresponds to six ETCS, according to the standards defined by the University of Porto – corresponding to approximately 162 hours of work by students.

The students are continuously challenged to put into practice the knowledge acquired, in contexts that are as close as possible to the real situations they could eventually face. This led to the adoption of a student-centred and cooperative teaching-learning strategy, aimed at providing the right conditions to put into effect the "doing" and "learning" skills, without neglecting "knowledge". Therefore, learning strategies based on the PBL are fully suited to these purposes and simultaneously encourages the continuous interaction between the participants, while learning and applying the contents of the curricular unit.

According to the study plan of the MESG, and since it follows the set of descriptors defined in the CDIO initiative (Berggren et al., 2003)(Crawley, Malmqvist, Östlund, & Brodeur, 2007), the BPM is expected to address the specific needs within the scientific dimension of the course, and contribute to instruct experts with the necessary skills to design, implement and operate complex technology-based service delivery systems. Through the BPM, students will hopefully acquire knowledge and skills that will enable them to succeed in the identification, characterisation, analysis and representation of processes associated with the provision of services supported by information technology. In this sense, the Business Process Modelling unit contributes to the development of skills based on the CDIO classification and belonging to the four groups defined.

This curricular unit, adopting a PBL learning strategy, aims to develop skills that we consider fundamental in the analysis, design, management and improvement of the processes supporting the services provided by an organisation to its clients. With this in mind, the BPM explore and discusses the concepts of “business model” and “business process”, before exploring the theme of “process orientation” and “process management”. In this sense, the curricular unit also aims to offer a framework (composed of a methodology and a set of tools) that allows students to create the model of a business involving service provision, while helping them identify, characterise and model the main processes of said business (always according the acquired knowledge). The students shall also be able to specify the information systems that support the business processes considered in these models. At the end of this curricular unit, students should be able to apply the methodologies, techniques and tools studied in real-life contexts involving customer-oriented services.

3 Teaching/learning methodology and strategies

3.1 Background

The mere presentation of information does not constitute a transfer of information per se. The information provided will not be of any use to the students, if they are not available to retain it. Finally, if the lecturer’s goal is for students to generalise this information, by applying it to new problems, then he/she should integrate and transform said information into knowledge.

Usually, the teaching of engineering follows a deductive process, where theory is provided first, followed by application. In this process, the lecturer is the source of knowledge and the students are the recipients, placing themselves in a dependent and passive position. The learning process usually involves the theoretical exposition of the subjects, the illustration of model application, the students’ practice in similar situations, the performance of extra-class exercises and, finally, the evaluation considering the same types of exercises. Very often, people pay little attention to why a task is being performed or how the content can be applied in real situations, as well as which practical problems could be solved and why students should be concerned with the given subject.

In this curricular unit, the educational methods used are conceptually compatible with the student-centred learning process and with an active learning logic. Accordingly, it includes the involvement of students in the acquisition of knowledge, through the discussion of multidisciplinary problems and their resolution, which should be performed as a team – thus ensuring a strong practical component, somehow transversal to the different subjects. According to our teaching experience, particularly that related to this curricular unit, we can acknowledge the positive influence of active pedagogical: increased motivation; development of 'high level' skills such as analysis, synthesis and evaluation; increased responsibility among students, namely concerning their own learning, which requires a permanently active attitude. In addition, we firmly believe that education in the field of engineering should follow a framework that promotes the connection with real situations of use/functioning (vocational guidance), always supported by a strong conceptual component and sufficiently comprehensive in terms of subjects (basic scientific training).

Different learning styles can generally coexist in a classroom. In this sense, the BPM classes involve different techniques to guide the training process: tutorial sessions, active brainstorming and cooperative and “long term” strategies approached with Project-Based Learning (PBL). This strategy aims to teach "processes" while putting into practice the skills of "doing" and "learning", without neglecting "knowledge". In fact, with the adoption of this strategy, the traditional theoretical-practical approach of problem solving was practically abandoned; it is now considered an integrative project of great scope, carried out throughout the entire curricular unit and developed cooperatively by the students. PBL can provide students with a richer, more "authentic" learning experience than other methods, since it occurs in a social context where interdependence and cooperation are crucial to accomplishing things. This context also allows students to avoid and resolve interpersonal conflicts.

Similarly, to student-oriented classes, where there is a great lecturer/student interaction, this approach enables lecturers to tutor their students individually thus guaranteeing the balance between different learning rhythms and enabling of a "working environment" close to the one they may eventually face.

It is important to point out the main criteria for the adoption of a cooperative learning strategy, such as the one considered in this curricular unit, namely when establishing teams of students for the development of a project:

- Positive Interdependence - team members have to rely on each other to achieve a certain goal: all team members have “equivalent value”;
- Individual responsibility - each member is responsible for (i) doing his/her part of the work and, at the same time, (ii) mastering the material associated to the work done by the team;
- Face-to-face interaction – team members ought to carry out the work (partially or totally) together, which requires adequate dialogue, support and brainstorming; Appropriate use of interpersonal/social skills - team members are invited to practice and perform leadership, decision-making, communication and conflict management functions;
- Regular self-evaluation/teamwork assessment - each team has to monitor their performance and identify what they can improve and/or what they should change or do differently in the future.

3.2 Project-Based Learning approach

Given the fact that the BPM course is an advanced course, the students are expected to feel motivated to adopt a more exploratory approach. In this sense, the PBL approaches have been explored with great success. The key motivation to consider the PBL was the adoption of a strategy that supports a learning approach focused on improving and broadening the skills of engineering students, namely in terms of: (i) understanding the role of theoretical and real-world discipline-specific knowledge in a multi-disciplinary, collaborative, practical project-centred environment; (ii) recognising the relationship of the engineering enterprise to the social/economic/political context of engineering practice and the key role of this context in engineering decisions, and (iii) how to participate in and lead multidisciplinary teams to design and build environmentally conscious and high quality facilities faster and more economically. (Fruchter,2001).

Based on the curricular design of the MESG, namely the fact that it follows the set of descriptors defined in the CDIO, the adoption of PBL strategies on core courses can actually benefit from the advantages of the the CDIO and PBL complementary models for engineering education (Edström & Kolmos, 2014). In conceptual terms, PBL is an instructional (and curricular) learner-centred approach that empowers students to carry out research, combine theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem (Savery, 2006).

This approach aims to help students adopt a “self-directed” and “self-regulated” approach in their learning, namely by making them responsible for organising and implementing action plans aimed at solving the challenge formulated. In addition, it seeks to create an active and integrated learning environment according to an interdisciplinary framework, thus promoting their involvement and increasing their motivation in the rediscovery of the issues addressed and the preservation of their relationship. Moreover, and in addition to the learning process itself, PBL encourages the ability to adapt to new situations and practises that require certain knowledge; reflection, research, experimentation and practical application are also encouraged, since they are crucial to form the citizens of tomorrow.

We share the same opinion as other authors concerning the importance of working in teams, namely in a context of a PBL approach (Fruchter, 2001)(Cinar & Bilgin, 2011)(Alves, Mesquita, Moreira, & Fernandes, 2012). The main objective is to explore group synergies, since the resolution of complex and multidisciplinary problems - such as the design business processes and service-oriented management systems - can actually benefit from said synergies. In that context, it is crucial to consider a set of activities related to management and planning processes. Students have to organise themselves in a team, be able to manage a project, make decisions and find solutions. The activities related to that require an concentrated and extended interaction between team members throughout the project. Thus, teamwork relies on a continuous interaction between group members concerning the project’s activities, purposes, knowledge and goals. However, having students working together could become a critical issue, since it demands much more effort than working individually. In fact, working in a team could be very challenging due to the coexistence of different interests, drivers, behaviours and opinions. As a result, the level of misalignment between team members could increase significantly, which could influence the efficiency and the quality of deliverables. In this context, students develop not only technical skills, but also transversal competences relevant for their professional practice in engineering, such as communication, problem solving, working with information, leadership, etc. (Peschges & Reindel, 1998)(Moesby, 2005)(Becker, 2006).

3.3 The Challenge

The challenge presented to each project team is to come up with potential business ideas within the domain of service-oriented organizations. Once completed the preliminary analysis of the feasibility of the business opportunity, the respective ranking is made according to the team's preference regarding the framework of the programme contents defined for the course.

Once the business idea is selected, the following challenge is detailing the value proposition and designing the business model. Then, students are asked to identify the critical processes stemming from the business process map. From this point onwards, the challenge consists in designing the main processes of the value chain, namely those in which there is a direct interaction with the customer. In this important design phase, multi-level modelling techniques are explored. Finally, each team must identify and specify what will be the main functional and non-functional requirements for the information system suitable for the execution and management of the business.

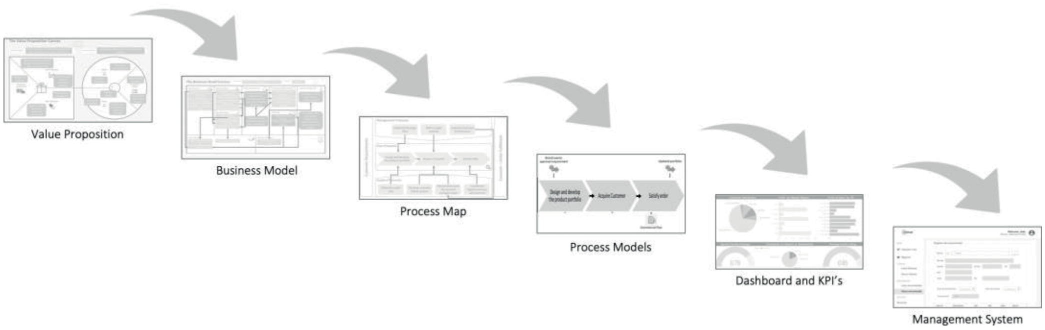

Figure 2: Overall methodology for the deliverables

Figure 2 illustrates the different phases involved in the generation of the different project deliverables. Figure 3 highlights some of the partial results generated by a team along the different project's phases.

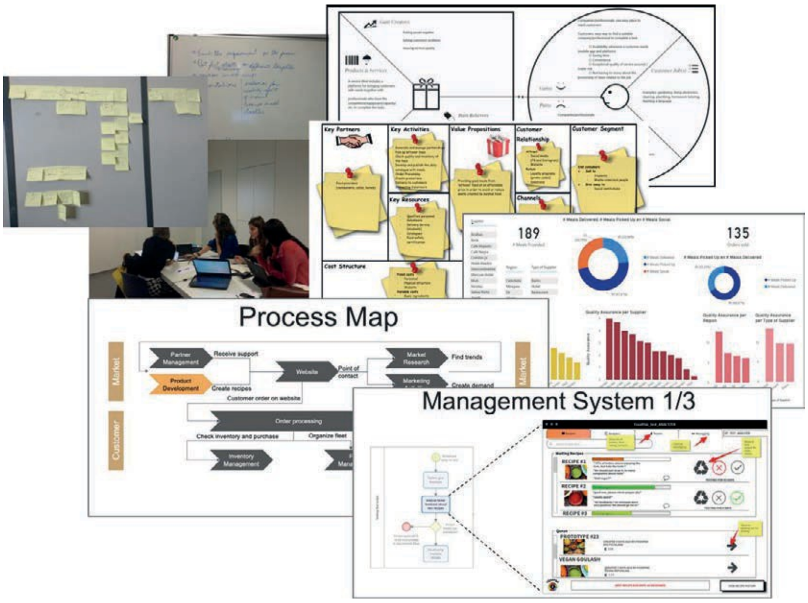

Figure 3: Snapshot of some of the outputs generated during project

In the development of the proposed medium/high complexity and long-term project, each team is expected to work as if they were part of an organisation/company. In other words, the team members play the role of employees at an organisation /company facing a big and important challenge: the analysis and design of the business processes, and the definition of the relevant supporting information system.

Besides facilitating the design and development of a new service-oriented business, supported by engineering methodologies and tools, the adoption of PBL and teamwork strategies can actually promote the development of teamwork skills, namely regarding coordination, integration of development activities, communications, interrelation elements and accountability.

3.4 Teamwork

The adoption of the PBL approach for larger groups could be challenging, but with adequate organisation and tools, one can ensure its effectiveness (Esteban & Arahal, 2015). Concerning the proposed challenge, we've established larger teams (between 8 and 12 students per team, three or four teams between 8 and 12 students, depending on the number of students enrolled in the course). In the first editions of the course, the students were allowed to select their own teams, but in more recent editions, we've decided to carry out draws, in order to simulate real contexts in which future graduates will be inserted - thus promoting the development of relational, communication and collaboration skills.

Teamwork can be perceived as challenging. Hence, and in the name of effectiveness, team members must actively focus on their objectives and think about ways of achieving them on a regular basis, always according to the teams work methods. At the same time, in order to ensure a good environment and to guarantee the well-being of each member, the teams must reflect upon the adequate ways to provides support, to solve conflicts and to address the overall social and emotional "mood" of the team. This way, teams are encouraged to use teamwork methodologies and techniques, in order to ensure adequate levels of efficiency and effectiveness i.e. teamwork ought to be based on a set of rules and methods. These rules and methods define: the responsibilities of each team member and the procedures and operating rules to be followed (e.g. rules associated with the preparation and approval of documents, the management of resources and activities/tasks, the process of operating and conducting meetings, etc.). Furthermore, each team is encouraged to use appropriate tools to support the proposed work. The use of IT tools is highly recommended, since it facilitates three key points for an effective teamwork: interaction and communication within the team, plan and coordination of work’s activities and information and documentation management (e.g. production, access, sharing and version control).

In the overall plan of the course, we dedicate some tutorial sessions to the presentation of methodologies, techniques and good practices related to a teamwork. The experience of past editions shows that these sessions have been very useful to ensure the efficiency of the team in terms of its organisation and implementation processes. As soon as the courses initiate, each team ought to hand over the assignment of tasks to the lecturer, as well as a document defining the roles assigned to each of its constituent members. Each team starts by preparing a document (called Team Quality Manual) containing: the different roles and duties within the team; the style manual, organisation and management of the documentation; the team's internal operating rules for meetings and decision-making processes; the overall project plan and a detailed short-term plan.

At the end of the course, each team shall submit a report (maximum 3 pages) presenting the organisation of the work, the methodology and sources of information considered, as well as the main problems encountered by the team during the development of said activities. The teams should also provide an overall assessment and possible suggestions for improvement, namely concerning the methodology proposed for carrying out teamwork.

3.5 Follow-up

In a certain way, during the course of the activities, the lecturer acts as a consultant to the "service-oriented organization" (team). In the end, when evaluating the results achieved, he/she acts as an auditor (the aim is to assess the degree of compliance of the work developed according to the applicable requirements and expectations). Each team must keep a record of the activities, namely: documents produced and their status, tasks planned, in force and completed and tasks carried out by each member (weekly periodicity). The teams are monitored at three levels:

Sporadic or informal - the lecturer observes the team during the activities, which helps identifying of the main issues that the team has to deal with; with this type of monitoring, he/she is able to motivate the team and clarify specific doubts that may condition or "hinder" the normal development of thework.

Request from the team - whenever the teams require some advice or mediation, they should request a meeting with the lecturer. Before any meeting with the team, the lecturer should have access to the corresponding agenda. In this sense, the team is required to previously define the issues that will be discussed with the lecturer (). At the end of the meeting, the team shall draw up minutes with a record of the issues dealt with, the actions defined, and the decisions taken.

Periodic or formal meeting – The definition of the study plan should include three or four follow-up meetings with each team. In these meetings, the lecturer informs the team about the issues to be analysed (e.g. process of implementation, results already obtained, work plan, etc.), often requesting information on a specific subject that they wish to analyse/discuss with the team; each team should send a document containing the state of play of the project regarding the tasks (completed and ongoing) and the documents to be analysed at the meeting. The main objective is to make the teams aware of the deadlines set for the planned actions. In these meetings, the teams usually get a lot of “feedback” from the lecturers involved in the follow-up, which is essential guide them in the right direction. The teams should send the respective minutes to the lecturers, within a 24-hour period

3.6 Final presentation and discussion

The final session for the presentation of the work carried out by the teams takes place for an entire day. Each team has a time slot of about 30 minutes to present their work. After that, the team and the “audience” (remaining students and the assigned faculty member) have a discussion period, limited to a maximum of 30 minutes. This final session is very important to consolidate the teaching-learning process. On the one hand, the team presenting the work has the opportunity to point out the technical developments in business and process modelling, through a presentation that ought to be dynamic and captivating. On the other hand, the faculty member assigned has the opportunity to explore and assess (from a technical-scientific point of view) specific issues that could eventually emerge during other presentations, besides making his/her own critical analysis. This session is also important to review the concepts, techniques, tools and methodologies explored and developed throughout the course.

4 Lessons learned and final remarks

It is acknowledged that the adoption of PBS practices and strategies lead to greater satisfaction of faculty and students. Indeed, in addition to learning process itself, PBL has the potential to prepare students more effectively for future learning because it is based on four modern insights into learning: constructive, self-directed, collaborative and contextual (Dolmans, De Grave, Wolfhagen, & Van Der Vleuten, 2005) (Mann et al., 2020). However, although the existing PBL research has confirmed that PBL is highly effective in cultivating students' collaborative skills, research on interdisciplinary curriculum design and implementation has been lacking (Hung, Dolmans, & van Merriënboer, 2019).

The experience obtained in this curricular unit, namely through the adoption of a pedagogical strategy based on PBL and teamwork, led to very interesting results. In fact, by contacting with the participants of previous editions and by analysing the "feedback" at the end of the projects - and taking into account the quality of the results obtained - we can infer that the majority of students showed high levels of participation, motivation and collaboration, while the proposed objectives have been successfully achieved. Hence, participants were able to meet the course's goals, by learning to share individual responsibilities in a working group, similarly to what is done in real situations. They learned to make justified decisions in the context of a project with goals and milestones, while playing the role of experts focused on solving problems collaboratively in a rational manner. Furthermore, the majority of the pupils was able to understand that their level of commitment has implications, not only in their own evaluation, but also in the performance of their peers, which creates an effect of responsibility.

Our experience from the involvement in this curricular unit in recent years, allows us to list some lessons learned that we consider crucial. Firstly, it is essential to encourage teamwork-oriented workshops with students. It is essential that they understand the need to implement simple mechanisms that enhance the resulting synergies with the various constituent elements of the team. In this context, the definition of organisational and operational rules and, in particular, of decision-making mechanisms are truly crucial. Secondly, it is very important for students to know the simple practices of project management, especially agile project management (emphasizing short-term planning, creation of sprints, etc.). Furthermore, it is very important to establish a self-assessment and peer review mechanism that is fair and meaningful in the team's performance.

Finally, yet importantly, we should point out the role and quality of the lecturers as fundamental elements to achieve the objectives set for the course. In PBL, lecturers are part of the students' journey of learning on multiple levels, and the quality of teaching ought to rely, among other things, on their ability to intellectually motivate the students and maintain a positive relationship with them. Hence, in order to obtain good results, lecturers shall keep clear channels of communication, motivate their students and preserve a warm, open, accessible, democratic and student-oriented relationship.

The experience of previous editions, together with the new reality in the field of services and the restructuring carried out with the inclusion of teamwork in a project-based environment (similar to real situations), allowed to develop crucial skills to the exercise of the engineering profession. In this sense, the methods and means adopted were proven adequate in terms of efficiency and effectiveness. Nonetheless, it is important to mention that the success of the aforementioned approach depends on the lecturer's attitude, namely in terms of thoroughness, professionalism, dedication, enthusiasm and communication with the students.

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PBL Implementation – Advantages and Disadvantages

Empowering English-majored Students at DUY TAN University through Project-based Learning to Upgrade their Graduation Theses

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Abstract

The paper aims at upgrading the quality of English-majored students' graduation theses by empowering English-majored students through project-based learning. The focus group interviews of 30 lecturers of English at Faculty of English, Duy Tan University and the survey of 72 fourth-year English-majored students were conducted to find out advantages and disadvantages that lecturers and students encountered in using PBL approach in teaching and learning. In addition, the paper showed the impact of PBL approach on the quality of students' graduation theses and suggested possible solutions to obstacles encountered by lecturers and students in employing PBL approach to improve the quality of students' graduation theses. Besides, in this paper a mixed-method study was conducted with both qualitative and quantitative analysis on lecturers and students to find out the advantages and disadvantages when implementing PBL. The results show that students were highly motivated by implementing PBL in teaching and learning (87.5% students' interest, and 62.5% high helpfulness of PBL to students' graduation theses). It is hoped that the paper will help students realize the essence of PBL at universities in Viet Nam so that they can improve their graduation theses better and better through PBL approach.

Key words: project-based learning, graduation theses, advantages, disadvantages, empowering
Type of contribution*:* research paper.

1 Introduction

Although Project-based learning approach was in use during the 1960s in Health Sciences Education cited by Hitt (2010), until the 21st century, integrated curriculum has become one of the most interesting issues in education all over the world. The educational trend is widely being used in most schools based on Common Core State Standard in The US, Singapore, Finland; therefore, a lot of advanced pedagogical methods have been introduced to meet students' necessary skills in the 21st century such as *communication, collaboration, critical thinking, creativity*. Among them is Project-based learning, the integrated learning which is becoming increasingly popular in schools, using lectures and direct instruction with more student oriented learning activities. In the same line, Solomon (2003) has discussed that PBL encourages students to develop their collaborative and investigating skills towards real world problems, thus adding value to their learning. Markham (2011) has considered that "*First, PBL integrates knowing and doing*". It means that students learn and apply what they already know to solve real problems by suggesting solutions or answers to the matter. As a matter of fact, PBL consists of an effective teaching and learning strategy to require commitment and greater responsibility not only from the students but also from the teachers, especially students have to realize that the knowledge gained by their own personal efforts will be much more meaningful (Masson et al., 2012). In Viet Nam, implementing PBL at all universities has increased remarkably for recent years because it can help students to overcome obstacles on socio-emotional skills and develop not only their knowledge but also their soft skills that are very useful for their future jobs. Duy Tan University, one of the leading private universities in the center of Viet Nam has applied PBL in teaching and learning since 2014 and initial achievements have illustrated the importance of PBL in higher education, especially in teaching International Business with imported textbooks (Nguyen et al., 2018). Since 2014, Faculty of English at Duy Tan University consisting of two majors: English for Translation - Interpretation and English for Tourism has implemented PBL in teaching and learning. Since the second year, all English-majored students have been required to be involved in three PBL sessions such as PBL 296, 396, and 496 in which PBL 296 consists of 15 periods and PBL 396 and 496 comprise 45 ones. Particularly, the well-trained teaching-staff with PBL approach have empowered fearlessly English-majored students through PBL has brought positive results in upgrading the quality of students' graduation theses; however, the PBL implementation has caused a lot of difficulties. The current study investigates 30 lecturers' perceptions toward empowering English-majored students through PBL and the survey of 72 fourth-year students to give proper solutions to obstacles in order to make the quality of English-majored students' graduation theses better in the future.

This study is intended to achieve the following objectives:

- To identify the advantages and disadvantages of English-majored students and lecturers of English at Faculty of English, Duy Tan University through empowering English-majored students with PBL implementation.
- To show the impact of PBL approach on the quality of students' graduation theses.
- To suggest possible solutions to obstacles of using PBL approach to upgrade the quality of students' graduation theses.

The research questions are formed as follows:

- What are advantages and disadvantages encountered by English-majored students and lecturers of English at Faculty of English, Duy Tan University through PBL?
- What is the impact of PBL on the quality of English-majored students' graduation theses?
- What are possible solutions to obstacles of using PBL to upgrade the quality of students' graduation theses?

2 Literature review

2.1 Overview on PBL

According to Kolb (1981), learning process is divided into 4 different basic types such as *observing and thinking, conception, experience* and *experiment.* In reality, everyone uses learning differently basing on their own level, knowledge, experience. Later, Bransford and Stein (1993) has mentioned PBL with long-term and interdisciplinary learning, especially accompanied with real problems. Next, Dewey (1997) has discussed that Project-based learning stimulates learners to investigate and discover what they were taught by working in groups or teams. Sawyer (2006) has showed Rivet & Krajcki, 2004's research that students in PBL classes get better scores than students in traditional ones. The reason for the better results is that experiential learning is considered as studying process through high practical and applicable projects such as designs, simulations, studying cases, from which students can get their own experiences to illustrate what they have already learned before (Edward et al., 2007). In PBL, Markham (2011) has proposed that students have to work in teams or groups to find out their own solution to the problem and then demonstrate their final work with digital tools to make high quality, collaborative projects. In Viet Nam, PBL has been applied widely in education since the beginning of the 21st century, especially in higher education PBL always plays an important role in not only helping students achieve graduation standards but also giving them opportunities to pursue their interests or find out their solutions to problems in their projects. Bui and Nguyen (2017) have mentioned challenges and solutions in the implementing PBL in English courses at Duy Tan University. Next, Nguyen et al. (2018) has shown students' better results thanks to PBL approach and imported materials in teaching and studying. In reality, learning English is an integration of both traditional methods and advanced ones and the main aim is how effectively students will use English in their future career; therefore, the study on empowering English-majored students through PBL to upgrade the quality of students' graduation papers is necessary and indispensable for higher education. It is hoped that the study will create open questions on PBL for further researches in the future.

2.2 Theoretical background

2.2.1. Definition of project-based learning

According to BIE (2016), Project-based learning (PBL) is considered as an advanced teaching method in which students obtain new information and get new skills while solving a complex question or problem for an extended period of time, within the context of a certain course. It is really a learner-focused teaching approach, different from traditional classes where teachers repeat the information. In PBL, the teacher acts as a facilitator, encouraging the students to do research, give questions and later apply what they learn so as to propose a feasible solution to a complicated problem. In brief, PBL is a dynamic approach to teaching in which students can explore real-world problems and challenges, concurrently developing 21st century skills while working in small collaborative groups.

2.2.2. Characteristics of project-based learning

Markham et al. (2008) suggested the main characteristics of PBL, aiming to assure the success of students' learning that means PBL "*refocuses education on the student, not the curriculum which rewards intangible assets such as drive, passion, creativity, empathy, and resiliency. These cannot be taught out of a textbook, but must be activated through experience.*" (Markham, 2011). In reality, PBL varies from classroom to classroom, therefore it is often characterized by the following attributes:

- In using PBL, the teacher provides all activities organized around a problem or challenge without a predetermined solution. Students will have to make up their mind to find out their own solution.
- PBL, a dynamic approach to teaching requires students to master important content of lecturers and know how to apply soft skills in doing the task.
- Empowering students through PBL encourages students to design the process for reaching their own solution by using their previous knowledge, soft skills and even technology.
- Especially, PBL requires a lot of things from students such as critical thinking, problem solving, collaboration, and various forms of communication.
- Besides, PBL also proposes the opportunity for students to examine the task from different perspectives using a variety of resources, separate relevant from irrelevant information, and deal with the information they gather.

- Students know how to work independently and take responsibility when they are asked to give their decision.

- Using PBL, Students often have chances to reflect on what they are doing and they can express their views or ideas comfortably because PBL always requires self-reflection, reflection on teamwork, and reflection on the conduction of the project.

- At the end of the teaching using PBL, groups of students will present their final products which are necessarily material are evaluated for quality. The final product results in high quality, authentic products and presentations.

- Different from traditional classes, the classroom using PBL has a more comfortable atmosphere that accepts errors and change. It creates a "constructivist" learning environment.

- Using PBL, the teacher is not a leader, and the role of the teacher is a facilitator rather than a task master.

2.2.3. Steps in conducting project-based learning

In order to implement PBL in teaching and learning, there are a lot of ways including the effectiveness of PBL approach by Hell et al. (2006) consisting of the elaboration of activities and a final product, the teaching – learning activity suggested by Markham et al. (2008) based on commitment and responsibility from both the teachers and the students, the effective teaching – learning strategy given by Masson et al. (2012) in which students are encouraged to seek solutions to issues of their daily life in educational contexts. As a matter of fact, PBL needs creativity and flexibility, therefore at Duy Tan university we often carry out 7 steps to get successful PBL

+ Step 1: The teachers involve their students from the beginning in order to attract students' attention.

+ Step 2: The teachers break down the topic into well-defined tasks so that students can understand each task well before participating in the PBL

+ Step 3: The teachers also propose students to have good plans, set goals, and define outcomes before conducting PBL

+ Step 4: The teachers divide his/her class into working groups with well-defined tasks.

+ Step 5: The teachers give students an extended period of time so that they can create a tangible artifact as an outcome.

+ Step 6: The teachers arrive at a conclusion PBL and give students some more minutes to prepare for presenting their final products.

+ Step 7: Students give their document and presentation to a public audience.

3 Methodology

3.1 Case description

3.1.1 Research participants

The study was conducted with 72 English-majored students from 3 fourth-year English classes at Duy Tan University in Da Nang, Viet Nam (two English-majored classes for tourism and one for translation-interpretation). Among them are male: 9.72% and female: 90.28% in the school year 2019-2020. They all are fourth-year students whose age ranged from twenty-one to twenty-three (93.05%) and from twenty-four to twenty-six (6.95%) (see Table 1 below). Most of them spend all their time on English to develop their English skills because they specialize in two majors: English for translation-interpretion and English for tourism. Besides, thirty lecturers of English who have ever used PBL in their teaching were invited to take part in focus group interviews.

3.1.2 Research instruments and contents of the questionnaire and the interview

Two research instruments which were in use to collect data are a questionnaire and focus group interviews. The questionnaire for students consists of two parts: the background and the content (see Appendix B). The former proposes questions about students' background information including gender, age. The latter comprises the questions on their interest in PBL approach and the impact of PBL on their graduation theses. The questionnaire was distributed to 72 students at the same time to garner the clear data on general information and their interest in PBL approach.

Regarding the focus group interviews, two main interview questions and follow-up questions (see Appendix A) were used to collect lecturers' in-depth information about obstacles encountered by their students and themselves when they used PBL approach in their teaching.

3.2 Data collection procedures

Seventy-two copies of the questionnaire were delivered to English-majored students in three classes, and all participants had fifteen minutes to give their answers to the questionnaires, and then seventy-two questionnaires were gathered.

Thirty lecturers of English using PBL in their teaching were invited to participate in focus group interviews carried out in Vietnamese and recorded for later analysis.

3.3 Data analysis

The results on advantages and disadvantages of PBL implementation collected from the focus group interviews of thirty lecturers of English at Faculty of English, Linguistics Institute, Duy Tan University were recorded and analyzed so that the most common ideas were chosen to show in the section of results and discussion.

The results of two surveys on students' interest in PBL approach and helpfulness of PBL to their graduation theses were collected to show how interesting and helpful PBL approach is to English-majored students so that the study could give the impact of PBL approach on students' graduation theses. In addition, possible solutions to obstacles of using PBL were suggested to upgrade students' graduation theses.

3.4. Research methods

The main aim of the study is to find out the advantages and disadvantages encountered by English-majored students and lecturers of English at Duy Tan University and give some possible solutions to these problems; therefore, a mixed-method study was conducted with both qualitative and quantitative analysis. The surveys by means of using a questionnaire and focus group interviews were implemented with 72 fourth-year English-majored students and 30 lecturers of English using PBL in their teaching. More importantly, the collection, analysis and presentation of the data were conducted thanks to the descriptive method to show the possible solutions to improve the quality of fourth-year students' graduation theses.

4 Results and discussion

4.1 Results of English lecturers' focus group interviews on PBL

After participating in focus group interviews, 30 lecturers of English at Faculty of English, Duy Tan University provided their own ideas on advantages and disadvantages of using PBL in teaching to upgrade the quality of students' graduation theses. The following are some representative lecturers' excerpts during the interviews

L1: *Well, most of my students are interested in participating in PBL activities. By empowering them through PBL activities, I can help them to give their own solutions to real-life situations.*

L2: *In my opinion, in order to deal with a problem, all students need both their knowledge and soft skills. Through PBL activities, students can have a lot of opportunities to practice and acquire soft skills which are very important for their future jobs.*

L3: *It seems to me that it's very good for all lecturers to use PBL approach in their teaching; However, time consuming makes me worried. Because it takes my students a lot of time to look for necessary information or materials for their project, and design it suitably.*

L4: *To me, PBL is a good approach, but I am wondering whether all lecturers are well trained for PBL activities. How about evaluating students' final product? By giving marks or remarks.*

L5: *Of course, PBL approach is very good, but the disadvantage is lack of students' interest on their project subjects. It is very difficult for students to prepare for the project they don't like at all. Consequently, lecturers have to give their students more optional subjects.*

L6: *Well, as you know the main concern that all companies are interested in is that the candidate has to get much experience in various projects. Consequently, PBL approach is considered as a good way for my students to acquire their own precious experiences.*

All lecturers' main opinions can be arranged in two aspects: advantages and disadvantages of project-based learning approach as follows

4.1.1 Advantages of project-based learning approach

First of all, PBL encourages students to work on a problem in depth, rather than covering many topics briefly. Especially, students are more engaged in learning what is necessary to deal with a problem or complete a project, rather the teacher makes up his/her mind in predetermined curriculum. These learning strategies are considered as important tools to improve learning. In addition, through PBL students can acquire and practice soft skills, and they can have a "taste of reality" by experiencing and dealing with real-life situations and problems before and after they graduate. In reality, company representatives always search for future employees who have worked on various projects, even if working on projects makes them delay their graduation. Furthermore, it is very important for candidates to be capable of communicating with other members of the team if they get the soft skills required. Besides, due to the contextual nature of the method students can retain content over memorization. Last but not least, PBL can help students make the best of diagnostic, informative and substantive assessments by doing the project work.

4.1.2 Disadvantages of project-based learning approach

Although using PBL can provide students great benefits and advantages, it also has some disadvantages that may occur while using this approach of education for the students. First of all, it is time consuming that most lecturers are always worried about. Designing an effective project-based learning often requires a large amount of time since it takes time to collect information and materials about the projects. Secondly, it is lack of students' interest. Sometimes this may occur in PBL because some students can feel uncomfortable in their project subjects which may distract their mind from the project. Thirdly, it is lack of dedicated and hardworking lecturers for their students. Not all lecturers are trained well for the application of PBL in teaching. But the PBL approach really needs hardworking staff dedicated to their students' projects. Fourthly, it is uncomfortable for students' different levels of ability. They may not sometimes feel encouraged to finish their projects in the allotted period of time. Finally, PBL can show other aspects of studying progress such as adaptability, ability of giving solutions, making final products, thinking in reality; however, teachers only give marks for students' final products, which decreases the good sides of PBL. As PBL is authentic learning, there should be an authentic assessment so that students' products can be estimated holistically.

4.2 Results of students' survey through thequestionnaire

Table 1: Fourth-year students' age and gender in three fourth year English-majored classes

Class	Female	Male	Age (21-23)	Age (24-26)	Total number of students
K22NAB1	26	3	26	3	29
K22NAD1	19	2	20	1	21
K22NAD2	20	2	21	1	22
Total	65	7	67	5	72
Percentage	90.28	9.72	93.05	6.95	100

Most of the fourth-year English-majored students (93.05%) are from 19 to 22, and only a few ones from 23 to 25 (6.95%). Most of them (90.28%) are female and male only occupies 9.72%. From the result of the survey, we can see most students have the same age (from 21-23) and the majority of them are female, therefore empowering students through PBL approach did not meet a lot of difficulties.

Followings are the surveys of English-majored students' interest in PBL and their remarks on the helpfulness of PBL approach.

Table 2: The survey of English-majored students' interest in PBL

Students' interest in PBL	No	%
Yes	63	87.5
No	3	4.16
A little	6	8.34
Total	72	100

Table 3: The survey on the helpfulness of PBL to English-majored students' graduation theses

Levels of the helpfulness	No	%
high	45	62.5
medium	20	27.78
low	7	9.72
Total	72	100

The survey in Table 2 showed that most of the English-majored students (87.5%) liked PBL, a few (8.34%) liked it a little, and very few (4.16%) did not like it. Consequently, it is certain that PBL attracts students' interest a lot because students realize that they themselves can get a lot of benefits from using PBL approach easily. In Table 3, we can see the helpfulness of PBL approach to English -majored students with the high level (62.5%), the medium (27.78%), and the low (9.72%). By empowering students through PBL, their lecturers give their students opportunities to develop their necessary qualifications such as creativity, critical thinking, collaboration, and communication which are very important skills for students in the 21st century.

4.3 The impact of PBL approach on the quality of students' graduation theses

Since 2014, Duy Tan University has applied English-majored students' outcomes including carrying out graduation theses and achieving 5.5 (IELTS) or 550 (TOEFL- ITP)/ 65 (TOEFL-IBT). In addition, PBL approach has been implemented more frequently at English-majored classes. According to the statistics of 4 years (from 2015 to 2018) on the results of English-majored students' graduation theses, we have the following figure

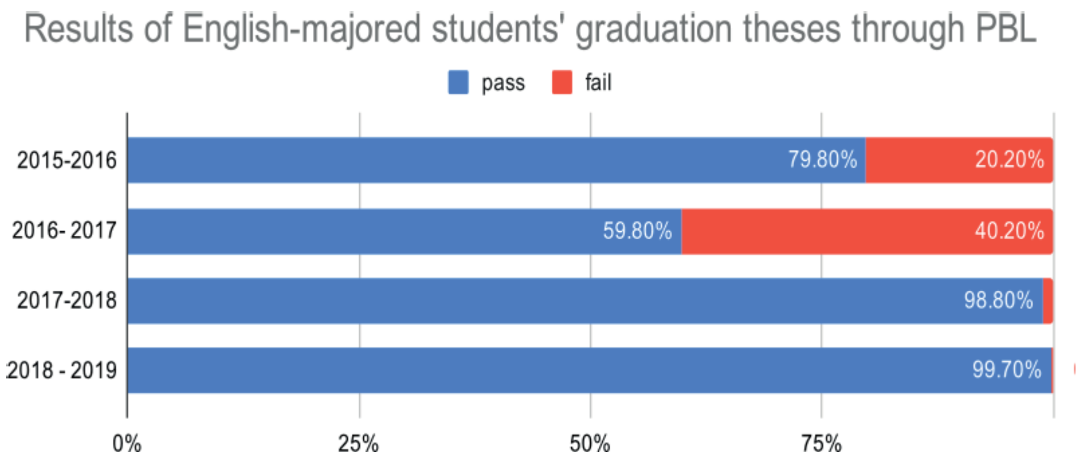

Figure 1: Results of English-majored students' graduation theses through PBL approach

The percentage of English-majored students passing the course is 79.8% in the school year 2015-2016 and up to 98.8% (2017-2018) and 99,7% (2018-2019) despite the low passing result in 2016 -2017 (only 59.8%). As can be seen, the passing ratio of English-majored students is extremely high. Graduation theses are really large and vital projects for all fourth-year students because students' qualifications can be shown through their final products, graduation theses which decide their success or failure during their studying years at university. In reality, PBL approach plays an essential part in students' graduation theses because PBL helps students get organizational skills which have already become a must at present and are developed during conducting their graduation theses as well. It's important to organize the graduation papers mentally as well as physically. Besides, PBL stimulates students to think out of the class and look for the new unusual ways of problem solving and students can express their viewpoint on the problem under study, therefore problem-solving skills are really necessary for students in conducting their graduation theses. Furthermore, PBL provides students ability to find information. In all researches, students have to look for the needed information themselves, not from their lecturers. The skill to find the necessary data is an extremely valuable asset for life, especially for their graduation theses. Moreover, PBL helps students know how to manage their time during doing the project and handing in graduation theses on time requires proper time managing skills, so students had better first estimate the time required for fulfillment of their graduation theses and then divide it into smaller and more manageable parts. Last but not least, PBL helps students develop communication skill which is very helpful for students to present their graduation theses. Most Vietnamese students often lack communication skills such as speaking, writing, and presenting even though their qualifications are quite good. In conclusion, PBL approach is really essential in improving English-majored students' graduation theses. Besides, students can get success in presenting their final products thanks to soft skills provided by PBL.

In addition to the usefulness of PBL, the results in Nguyen et al. (2018) have shown the better effects in using PBL approach at Duy Tan University. The results of PBL classes in PSU Vietnamese Business Administration Collaboration Program prove that 100% of PSU Business Administration Collaboration Program's students has passed the course for the 2014 – 2017 period. In comparison with the results of English – majored students' graduation theses, we have achieved 99,7% passing graduation theses in the academic year 2018-2019. It is obvious that PBL approach plays an important part in teaching and studying in higher education, especially in conducting students' graduation theses.

4.4 Possible solutions to obstacles to upgrade students' graduation theses

PBL approach is a new teaching and learning one which attracts teachers and learners; however, it also brings out some obstacles during its implementation. First of all, the amount of time is always limited, so the teacher has to design his/her teaching plan properly by giving students small tasks with their good preparation at home. Secondly, the teacher must be a facilitator who can create opportunities for students to study through various activities, encourage them to discover, apply, value others' ideas rather than impart knowledge from textbooks. It means that they teach their students how to question, how to develop hypotheses and strategies for locating information, even they become co-learners. Consequently, the staff of lecturers should be trained well with necessary soft skills and active teaching methods before students' training courses. Thirdly, attracting students' interest in PBL activities is very important, therefore the teacher should give students interesting activities related to subjects in real life. Fourthly, students' different levels can make PBL activities more difficult, but the teacher should arrange small groups of students with both good and bad ones so that they can help one another and learn a lot from others. Finally, proper assessment for PBL approach is very important because it is not right for the teacher to give only marks for PBL activities. As a matter of fact, students' self-assessment and the teacher's assessment play a vital part in PBL activities. At the end of PBL activities, the teacher can interview students so that students have chances to show their experience and challenges during conducting their PBL activities and the teacher can encourage students to set higher objectives for their next ones.

5 Conclusion

PBL approach has become very popular in the world for a long time, and its role is indispensable for teaching and learning in the 21st century. To get success in using PBL, lecturers must master advantages, disadvantages of PBL approach and their flexible roles in using PBL. Through the focus group interviews of lecturers and students' surveys on their interest in PBL and its helpfulness, we saw obstacles when using PBL approach and suggested possible solutions to them. In addition, the importance of PBL in teaching and learning was discussed and the study also showed that PBL is very helpful for English-majored students to upgrade their graduation theses. Thanks to necessary skills through PBL approach, English-majored students can feel self-confident to conduct and present their graduation theses. In conclusion, the impact of PBL is very essential for English-majored students and lecturers should empower them through PBL activities so that the quality of students' graduation theses will be improved.

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7 Appendixes

A. Questions used in the focus group interview for thirty lecturers of English

1. What are advantages and disadvantages of English-majored students and lecturers of English at Faculty of English, Duy Tan University by empowering English-majored students through PBLactivities?

2. What are possible solutions to obstacles of using PBL approach to upgrade the quality of students' graduation theses?

B. Questions for students' survey questionnaire

1. What is your age?
   - 21
   - 22
   - 23
   - over 23

2. What is your sex?
   - Male
   - Female

3. Are you interested in PBL approach?
   - No
   - A little
   - Yes

4. How helpful is PBL to your graduation theses?
   - high
   - medium
   - low

Opportunity Gap and Women in the Energy Infrastructure Workforce

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Abstract

The Bureau of Labor Statistics (BLS) predicts above-average employment growth for jobs in the construction industry. And despite the majority of entry-level jobs in construction requiring a high school diploma or less, median annual wages in the industry are over 8,000 dollars higher than other industries (Torpey 2018). Despite this growth and relatively high wages, women are severely underrepresented: just 3.5 percent of workers in the construction occupations are women while women make up 47 percent of the labor force. Career and Technical Education (CTE) in high school can provide an avenue for increasing the participation of young women. Through a Researcher Practitioner Partnership (RPP), a team of teachers, trades educators, and administrators from high schools, community colleges, and apprenticeship centers sought to increase access through a virtual design and construction STEM (Science, Technology, Engineering, Math) career pathway program. The team explored whether a Project-based Learning (PBL) approach in Virtual Design and Construction (VDC) is a feasible method for woman- focused CTE. We found evidence that targeted recruiting through a feminist positive pathway to create a critical mass of female participants in conjunction with PBL can offer an opportunity for women to enter a traditionally male-dominated field. Furthermore, our study calls for continued theory development into and provides evidence that higher concentrations of women have the potential to increase the industry's focus on safety, environmental protection, and labor standards. We argue that the lack of female representation is due to an opportunity gap for young women to learn about and join high-skill high-wage occupations.

Keywords: Workforce, Energy infrastructure, Social justice, Ethnography, Tradeswomen
Type of contribution: PBL research

1 Introduction

We posit that a gap in women's participation in the STEM labor force and STEM-CTE education is not a personal 'choice.' Iloh (2019) proclaims individuals likely receive indirect and direct messages about higher education opportunities and expected pathways. These messages work as barriers to the high-skill high-wage energy infrastructure industry occupations (Tarantino 2016).

Hegemonic masculinity in STEM-CTE careers and pathways perpetuate enrollment of young women into traditionally female-dominated sectors (Bonilla 2020). These forces actively exclude young women from an industry that, according to Kellie McElhaney, is male- dominated, but finally addressing the gender pay gap, “with women earning 93¢ for every male dollar... a stark difference from the business average of 82¢ per dollar.” Although this narrowing gap has experienced more progress in construction, many women are left out of this promising industry.

In this paper, we make three important contributions. First, we recognize that the underrepresentation of women in the STEM labor force stems from a variety of sociocultural realities. Second, we aim to break down these barriers to women’s participation by developing a unique CTE experience focused on providing a feminist learner-centered environment. Lastly, we document the effects of increased women participation and inclusion in a CTE experience. Specifically, we examine whether a Virtual Design and Construction Project- Based Learning (VDC- PBL) approach is feasible for creating a woman-focused CTE experience by drawing on rich partnerships with labor unions, affinity-based trade groups, and educational institutions spanning the K- 12 and postsecondary systems (K-14).

We were able to co-create an idealized feminist education using Project Based Learning and an enduring Research Practitioner Partnership (RPP). To disrupt the traditional power dynamics in the classroom; the research-practitioners intentionally created a learner-centered environment of construction feminism in which the young women took ownership of their VDC learning through group based projects and interactions with a variety of construction industry actors. We introduce the feminist learner-centered environment through a focused 'over-recruitment' of women into the program as lecturers, mentors, and student-learners. Our approach was centered on a feminist approach through the use of critical mentoring and support throughout the course. This specific and intentional mentoring by tradeswomen and researchers were key components of the feminist intervention modifying workforce VDC originally conceived by Tarantino and colleagues (2016). This program design allowed the researchers and community partners to curate and contribute to a tradeswomen-centered curriculum and pathway that at its very essence worked to tear down barriers and the resulting opportunity gaps for women in the trades.

As a result of this feminist approach, we observed a change in gender role perceptions and an unexpected outcome of the education process. We find preliminary evidence of a greater interest in and understanding of workplace safety, environmental protection, and labor standards. This finding suggests that there is potential for all workers in the industry to benefit from the increased presence of women. For example, the construction industry has a high rate of injury and is often implicated in adverse environmental and community impacts. We saw preliminary evidence that the participants had an increased awareness of a need in the construction industry for a cultural change towards safety, environment, and society. For example, many of the construction management programs have rebranded using variations of "sustainable construction" to highlight this need. Our finding suggests that all workers stand to benefit in the industry and women would likely see higher wages in a sector that has higher union density in some geographic regions.

This paper is organized with a point of departure and a review of theories of education, by our intervention, followed by the methodology of our research, the observed results, and we then conclude with a discussion of the lived experience, research limitations, and ourrecommendations.

2 Theory review

Montoya and colleagues (2018) found that underrepresented youth perceive the building industry (including the energy infrastructure industry) as a career pathway to higher education when given an opportunity to learn VDC through PBL. However, they observed a multi-step mechanism that limits the participation of women in the building trades; an opportunity gap (Ladson-Billings 2013) creates a perception that the building industry does not lead to advanced STEM degrees, and that forms a barrier for young women applying to building trade apprentice programs. Young women's limited access to careers in the energy infrastructure industry can be summed up by Iloh's 2019 research on college 'choice' models. Iloh proposes a model that predominates privilege as a driver of choice and that is a starting point to showcase the building trades as the pathway to STEM careers that it is.

The current ratio of women in construction education programs is 14 percent (Lufkin et al. 2014); and 3.4 percentof building tradespeople (Hegewisch 2019). Through ethnography andpriorexperiencein the building trades industry, the authors experienced the low numbers of women in both the building industry and in the pipeline courses which function as the predominant feeders to this industry. Much of the research that has been done to uncover the toxic work environment in the building industry sheds light on issues that extend into the secondary and post-secondary classrooms. There are gendered education pathways (Bonilla 2019). Due to such low numbers of women, the authors were able to teach a significant percentage of women in CTE career pathways courses in the Silicon Valley of Northern California. Women in secondary CTE courses are around 3 percent, this means that in a typical high school CTE course we would expect to see fewer than 2 women per class. Using 2006-2010 data from Affirmative Action/Equal Employment Opportunity education plans, the post-secondary student profile is typically 99% male and predominantly white and Latino, which is also true for the construction industry in this region—Fig. 1 shows one of the Workforce VDC teams that fit this demographic. Even fewer women complete the program. With such low numbers, women's exclusion in the industry begins before they even consider future careers. Secondary education is a crucial moment to disrupt women's social exclusion through Workforce VDC, which at its core employs inclusion and agency through its pedagogical framework.

Tarantino et al. (2018) envisioned a pedagogical framework that was set in motion in 2018. Using theory from Fruchter's PBL at Stanford University School of Engineering, the workforce VDC framework worked to directly disrupt the current trend of excluding young women through its key component of mentorship.

The social circumstances that help to exclude women from this industry are examined by Kniveton (2004). Kniveton considered motivations and influences of career choice for students in rural and urban England. The research in England corroborated Iloh's assertions that "the greatest influence on students' choice of career was their parents, followed by that of their teachers." Furthermore, in England, there is a peerage factor, firstborn students' careers were heavily aligned with their parents and that of younger children were influenced more by their older peers than their parents. This follows with Willis' seminal ethnography that was also situated in England, Learning to Labor, where the 'lads' follow the lead of their parents and peers (1977). The role of these peerage influences in San José is not clear, however, we are aware of the possibility. The research in England added a layer of depth by identifying that their findings may be a result of "the limitations of power of unions, and the virtual elimination of apprenticeships." The role of unions and apprenticeship education is at play in San José and the idea that unions replace the influence of peerage is an interesting note.

With limited apprenticeships and dwindling union influence, Vuolo and colleagues (2014) explored pathways from school to work using a longitudinal youth development survey. They examined the role of factors to distinguish youth who establish themselves in careers and those who flounder; these factors are: Adolescent achievement orientations; Experiences in school and work; And, sociodemographic background. The students were divided into four school-to-work pathways from ages 18 to 31; two groups attained careers through post-secondary education (via Bachelor or Associate - vocational degrees) and two groups did not attain vocational degrees (distinguished by attempting college without completion). They found that reduced “floundering” was predicted by factors of academic orientation, socioeconomic background, and steady paid work during high school. We see support for the findings by Vuolo and colleagues in an earlier study by Kerckhoff and Bell (1998). They found that in order to become established in occupational careers some workers obtained associate degrees or vocational certification—we see this as indicating an intuition on the part of workers that these degrees reduce floundering. Strengthen this notion, Kienzl (2005) notes that those earning associate degrees show substantial payoffs. Completing some college, whether at a four-year university or at a community college, received near-equivalent wage returns. These factors appear consistent with the privilege-choice theory proposed by Iloh— those more privileged are likely to obtain education and therefore fulfill their 'choice.'

Women leaving the male-dominated occupations is the ‘‘leaky pipeline’’ (Frome2006, NCES 1997, Oakes 1990). The leak is repeatedly found in studies that examine gendered occupational aspirations in the traditionally male-dominated fields. Frome (2006) studied 104 18-year-olds who were surveyed twice, at 18 (1990) then 25 (1997). The study's young women who initially aspired to male-dominated occupations lost these aspirations if they also desired a family-flexible job, as can be seen through gender research is common with women (Anderson et al. 2017).

Looking at the feminization of workforce education from a policy standpoint, there is a need in the feminization of workforce education to provide services for childcare, emergency cash assistance, mental health services, and domestic violence services (Anderson et al. 2017). A number of centers focus on policies for women as a workforce and some specifically the construction workforce, some of which we have been in contact with and or are finding we parallel and share some contacts, examples, the Rising Sun: Center for Opportunity, Tradeswomen Inc, Women’s Equity Center, and the National Center for Women’s Equity in Apprenticeship and Employment. An open question is what relationships tie together women’s labor education, leadership development, and movement building—for now, the answer is collaboration along these relationships and providing labor education through a social justice curriculum (Twarog, Sherer, O’Farrell, and Coney 2016). There are barriers in the education system that are outside our reach, such as prerequisite courses. The education for electrical workers requires that students have begun a STEM education pathway as a prerequisite to applying to the apprenticeship (IBEW-NECA 2020). Possibly schools do not perceive CTE students as needing STEM prerequisites.

There have been gender issues in construction that over time push many motivated women out of the trades, at the forefront is gaming of affirmative action rules to meet the employer's minimum legal requirement; there are complacencies throughout the system that short women the number of work hours they were offered (Wright 2019). Occupational segregation by sex is practiced throughout the world and it is a concerning practice that is not usually practiced for the benefit of the women (Anker 1997). Anker uses gender theory to propose that policy solutions are necessary that reduce family responsibilities, remove gender stereotypes, and that increase educational opportunity. There are studies that look at women in cultures outside the northern European cultural context; Russo looks at craftswomen in the Indian continent marketplace—there, a local pattern of female strength can be found that differs from the globally enlightened narrative of perceived weakness, further complicating the narrative of women (2018).

Universally, it is clear that low wage women are vulnerable to wage theft and that can be prevalent in the construction industry when policy protections are not in place (Gleeson, Silver Taube, and Noss 2014). Low wages can lead to criminal activity; a union job in construction is a pathway needed for women to move from incarceration to earning a living wage (County of Santa Clara 2008). These are pieces of the narrative and there are many gaps, more research is needed to understand the educational experiences of women in the building trades (Hegewisch and O'Farrell 2015) and more policy work is necessary from those labor unions that have not finished development of a gender democracy (Kirton 2017). A recent study showed that contractor lead apprenticeship programs, that did not work with a labor union, had an exceptionally low graduation rate (Illinois Economic Policy Institute 2020). In collaboration together, then contractors and unions are better able to address the widespread hazards that cause work-related injuries to construction workers (Boatman, Chaplan, Teran, and Welch 2015). In a similar approach, a joint collaboration of contractors and unions could better address a feminization of construction workforceeducation.

3 Workforce education model

We created a learner-centered environment of feminism around young women through thoughtful intentional recruitment of women mentors. The feminist environment gave the impression that the construction industry has a higher percentage of women than is actually the case. Our intention is to bring a level of comfort to the young women that allow seeing oneself in the construction industry in similar roles as the women mentors. The idea of a feminist learner- centered environment was discovered through discussions with Meg Vasey at Tradewoman Inc.; Meg is a lifelong advocate for women in the trades and is a union journeywoman electrician. Through Meg's guidance, we focused to give women a voice and were cognizant of a different lens that these young women would view the construction industry through, and made ourselves open to observing that lens—in Fig. 3, a female breakout space.

The experiment platform is an education model formed from a merger of two programs that reside in the same hallway at the Stanford Sustainable Design and Construction program. One is a well-known Executive Virtual Design and Construction program that over the past decade has successfully through learning-by-doing provided hundreds of executives and their teams around the world a refresher and update in construction project planning theories. The other is the equally well-known graduate-level Architectural-Engineering- Construction Global Teamwork program that over the past thirty years has through project-based learning taught generations of graduate students around the world to collaborate through a virtual presence. We literally took the lecture slides and phases of the VDC program and combined it with the virtual collaboration mentored project-based learning format and milestones of the AEC Global program. When we directed our merged program at the workforce, we termed it Workforce VDC.

As Workforce VDC, the program gained two new foci, one is feminism and the other is social justice. As a workforce education program, the authors were free to explore the topics, given the workforce focus in the curriculum on optimizing, for labor protections and safety as opposed to profit margins. These goals fit with the ideals of the unionized apprenticed workforces in construction, a high wage, high skill, and an exceptionally productive workforce. To introduce social justice in a clear structure, Dr. Anthony Kinslow II, a Stanford doctoral candidate, provided curriculum development based on his undergraduate engineering education at North Carolina A&T State University.

In feminism, Alissa Cooperman, also a Stanford doctoral candidate, provided curriculum development. Alissa outlined a technical education around social goals and interesting games. For example, each year, Alissa provides a guest lecture of engineering fundamentals that includes labs such as a catapulting of items with different weights. The intention is to make engineering accessible and fun. The students can take the engineering as far as they would like and there will always be a depth of mentors to support that pathway— in Fig. 4, students present their project idea to a virtual panel of mentors. For example, one young woman took an interest in electrical calculations and by the conclusion of her project she was beyond the remaining casual knowledge on the topic by the civil engineers in the room. The program is not intimidating; it is rigorous but there is not that certain type of masculine gatekeeping.

The Workforce VDC program became a popular testbed in the department to explore these social issues that form thorny problems in civil engineering. The social justice component as presented to the workforce students took a view to the community around students—we asked the students to observe their community, describe a problem, and then develop a potential solution to that problem.

In operation, the Workforce VDC program contains three overlapping programs: There is a twelve-month program for educators; There is a nine-month program for secondary students; There is a five-month program for post-secondary students. The twelve-month educator program is based on the VDC executive program's three phases of summer introduction, fall-winter-spring implementation, and then a May reflection on findings and lessons learned. Those educators during the fall-winter- spring implementation are teaching the nine-month and five-month secondary and post-secondary programs. The secondary students start in the fall and continue for nine months while the post- secondary students start in the winter due to a need to align with college quarters or semester.

The curriculum itself consists of engineering and trade skills. As described in the methodology section, we divided the program components into certificates, units, and credits. We have a pathway model from secondary through apprenticeship, to post apprenticeship, with a potential upper education achievement of graduate school—see Fig. 5 for our working idea of this pathway. We follow with this pathway a stackable credential approach to allow students to exit the pathway with their credentials documented and re-enter the pathway at a later time or at a different location without losing ground in the pathway. We have seen success in piloting best practices in the pre-apprenticeship side of this pathway and are transitioning to focus on developing post apprenticeship pathways; there is good early feedback on acceptance from potential collaborating universities. The Engineering component includes Science-Technology-Engineering- Math skills embedded in a narrative of Architectural-Engineering-Construction design and planning skills—in Fig. 6, 7, and 8 the students build their skills through mentored feedback. The trade skills component follows a career technical education, however, we maintain this at a novice level to respect a need for secondary students to focus on academic education. We are well aware of the exploitation that occurred through vocational education programs (Groeger 2017 2020). Further, there are indications that workforce education programs in Europe have a lead in regard to gender equity and academic equivalency (Hansen 2011). As said by Professor Fischer, a construction engineering theorist at Stanford, *“you are not training workers, you are educating the workforce.”*

As a result of participating in the Workforce VDC program, the students gain a lasting network of mentors and contacts in the industry, academia, labor unions, and public policy. We think we are activating elevations in Maslow’s hierarchy of needs (Maslow 1948). We bring a sense of belonging as well as a higher level of prestige to the students. Disrupting and reframing these pathways then allows students to rise to the academic performance and community actualization to meet each student's potential.

4 Research methodology

The authors implemented a Virtual Design and Construction (PBL) course following a template inspired by the Stanford PBL format Architecture-Engineering-Construction (AEC) Global Teamwork course. That course is based on a mentoring education format; students are given a constructed mentor relationship through which they learn technical skills, theory, and what it means to have a particular profession (Fruchter and Lewis 2003). The strategy is for the student to be the center of activity at times and peripheral to the mentor at others. Students see themself in the profession of the mentor and oftentimes continue with courses in the profession. Mentoring is both in-person at specific program events and as teams and individuals through innovative collaboration technologies (ICT) (Fruchter, Ponti, Jungbecker, and Alfen 2007). Through ICT, the AEC Global Teamwork course scales to an international and cross-disciplinary network of students and mentors in multiple 'social worlds.' This scalable platform has hosted numerous research projects over the past twenty- five years of operations, such as the role of multiculturalism on team success (Frank and Fruchter 2014) and modeling building CO2 levels for occupant well-being (Gray and Fruchter 2017).

This research relies on a Researcher Practitioner Partnership (RPP), which is a type of action research that involves long-term collaborations between colleagues of practitioners and researchers. These partnerships are fundamentally about bringing relevant and often on-demand research to bear on contemporary problems of educational practice (Ahn 2019, Gutiérrez and Penuel 2014). Our RPP included teachers from secondary and postsecondary institutions in addition to organized labor leaders who served as partners for this work. The postsecondary institutions included apprenticeship, college, and adult education. These are four high schools, two community colleges, three apprenticeship centers, and one adult education program.

To provide input to the research project, the RPP engaged many figures from the construction industry. Community participants included over one hundred leaders in education, union labor, policymaking, and construction businesses. Every three months over several years, the community participants met for a morning of reflection, collaboration, and planning of the next steps. The researchers attended these meetings to build community input and provide feedback on the research. This group is the Santa Clara County Construction Careers Association (S4CA); Montoya (2018) describes this organization and Fig. 2 provides an updated graphical map. The S4CA is predominantly the Santa Clara County Building Trades Council member labor unions, construction businesses that are signatories to labor union agreements, policymakers of public prevailing wage infrastructure, and consumers of a unionized wage workforce on secondary and post- secondary education infrastructure.

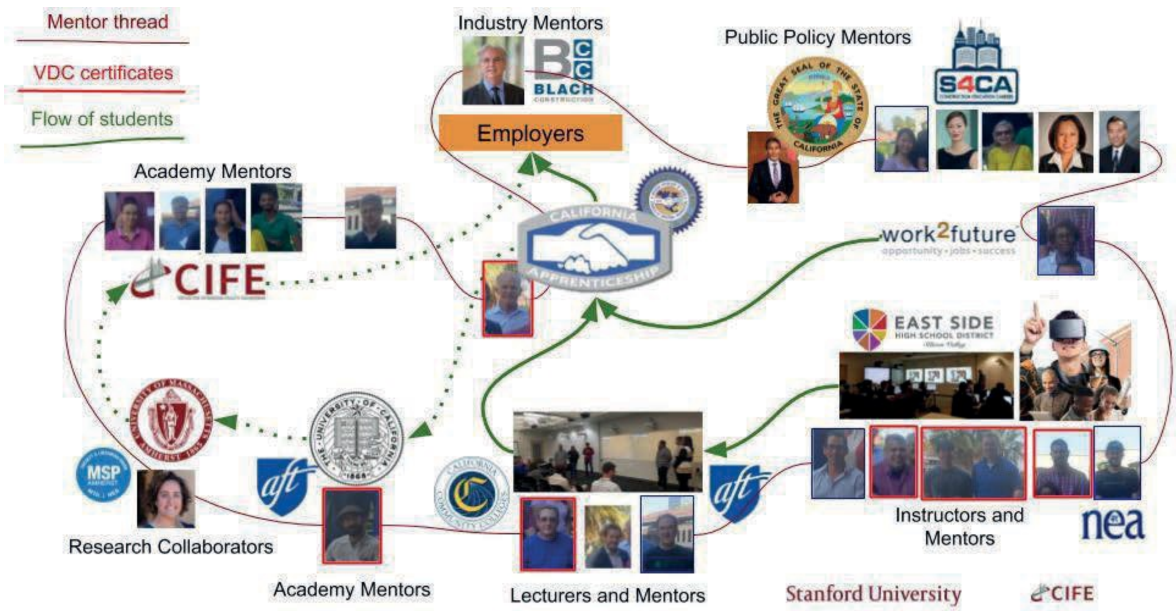

Figure 2: An evolving network of community participants, researchers, and practitioners. The participants represent each stop in the workforce pathway from education, to employment, to public policy, to labor standards oversight.

As a measure of the intervention effect on the opportunity gap, Fruchter's engagement metrics provide indicators of student opportunity; we looked for instances of engagement, disengagement, side conversations, gaze foci, and use of technological tools (2007). Data collection was through our roles as participatory action researchers and ethnographers. Through participation as mentors and instructors, we were able to analyze and code student artifacts such as PBL presentations and recordings of virtual mentoring sessions. Less observable of Fruchter's indicators, such as gaze foci, were understood within body-language feedback. At the conclusion of each event and at each of the four milestone events, the ethnographers compared their observations of artifacts and discussed their meaning. These observations and discussions were then compiled and were published as a peer-reviewed conference paper. The time in observation for the researcher to-date is 265 hours over 41 events which are over four cohorts (2017, 2018, 2019, 2020); in addition, there are 25 hours of dual enrollment and 25 hours of post-secondary classroom observations. The time in observation for the practitioner to-date is 760 hours in the classroom over three cohorts (2017, 2018, 2019) and 200 hours over 23 events which are also over four cohorts (2017, 2018, 2019, 2020), and again, in addition, there are 50 hours of post-secondary classroom observations. In total, the researcher and practitioner were in participatory ethnographic observations for over 1,300 hours over the course of four years. In addition, the authors pull coded ethnographic data from feedback and informal interviews from another dozen colleague researchers and practitioners that are participants in the ethnography through their everyday roles as mentors andinstructors.

The feminist intervention was the continued research situation as defined in Tarantino et al. (2016) and as piloted in Montoya et al. (2018). To reiterate here, the experiment platform is situated in teaching Fischer's Virtual Design and Construction theory (Kunz and Fischer 2005) as a STEM skills course. In Montoya et al. (2018), the VDC theory was modified with a social justice theme to carry the technical skills with a narrative and taught to the students as an intervention. The social justice theme continues in the current iteration of the program. The new intervention in this current study is the addition of feminism to the VDC theory. Following the project-based learning format, the feminism component was added through a more prominent role of a dozen female role models from leadership roles in industry, engineering research, trades, and technology. Pragmatically, this emphasis took the form of women-only breakout sessions at the October BIM Bootcamp, and strong female leads in the virtual mentoring and at the in-person Dry Run and Final presentations.

The student cohort demographic is within the San José metropolitan region, which is the tenth- largest city in the United States. That region has a racial demographic approximately evenly divided between Latinx, Asian, and White; half of the homes speak English as a second language. The region has the highest per-capita gross domestic product of any metropolitan economy (Pulkkinen 2019). That said, the region is not without disparities. The student population resides in a region that has one-tenth the rate of admissions to top-tier universities as neighboring affluent communities; A typical classroom has thirty-five students taught by a single teacher; Secondary schools graduate 500 students per year. The population is predominantly Latinx (50 percent) and Asian (40 percent); in addition to being lower income. 50 percent of students qualify for free and reduced-price meals compared to 10 percent of students in an affluent neighboring district. The academic performance of this population is 90 percent of the metropolitan mean, 80 percent of an affluent district, and surpasses the performance of some outlying bedroom communities (ed-data 2018). Racial disparity, social justice, and environmental justice aside, this is a well-performing though distinctly working-class demographic—it is not a demographic of privilege, we expect to have a situation of limited choice.

Taking a sample of the more active mentors provides a snapshot of their demographic: A third of mentors are women; The mentors are mostly educators (38 percent) and tradespeople (31 percent) with the participation of industry business practitioners (15 percent), and Workforce VDC educator program alumni from 2017 and 2018 (16 percent); Racially, the mentors are White (46 percent), Asian (31 percent), Latinx (15 percent), and Black (8 percent). The regional demographic for women is comparable; 31 percent White, 38 percent Asian, 26 percent Latina, and 2 percent Black (Office of Women's Policy 2018). The mentors represent typical roles in the construction industry, these are technologists, construction managers, educators, lawyers, public policymakers, union labor leaders, social justice champions, civil engineers, and tradespeople.

5 Observed situation

Three young women from a pair of secondary schools provide our insights into the feminist potential of the Workforce VDC program.

It was one of these young women that initially brought awareness to her perspective as a young woman in the workforce VDC program. She explained to the researchers that she could see a role for herself at her dad’s employment on a construction site. This was a role that at the start of the program she did not feel was a situation that included her.

A second young woman demonstrated through her actions a difference in expectations for young men versus young women. This student developed a cost estimating tool using spreadsheet software. She used spreadsheet coding to turn her estimate format into a reusable program. This was actually a pair of young women working as a team. The assignment was to calculate the cost of their team's proposed social justice mitigation—neither a spreadsheet nor equations were required. These young women asked mentors for advice then took their own initiative to develop a solution to the problem they were presented. Together they supported each other and gained strength to create something they otherwise did not see themself working on. Their work was excellent, surpassing some of the coursework produced by Stanford civil engineering graduate students—in Fig. 9 the young women's spreadsheet and their public recognition.

Their use of spreadsheet coding and an ability to format the spreadsheet into a coherent layout is not as universally understood as one in the civil engineering field might expect. In separate research, one of the authors observed a recent graduate of a regional civil engineering program, who was respected in his field office, use a calculator to sum a list of values and then entered that sum in a spreadsheet—these young women had outperformed that civil engineer. There was a confidence in these young women in their footing in technical topics alongside their male peers.
Confidence was a recurring theme; the third young woman took on a leadership role on a team of four young men. Under her leadership, they developed a study of homelessness in Silicon Valley, see Fig. 10. They then proposed an affordable housing solution that included both a design for housing units and a design for a community of the housing units. Her role is explained by her VDC instructor:

> ***“For the last two years, due to their extraordinaryresilience and creativity, our female VDC students have become the de facto leaders for their teams. Without a doubt, the entire team looked to them to set the pace for the entire project. In fact, Emily is consistently referred to by her team as 'our fearless leader.' ”***

It was through this experience that this young woman approached the program lecturers and asked for a letter of recommendation to accompany her university application. Through the program, she had seen the opportunities for her in public infrastructure professions and she had decided to apply for these degree programs. In the subsequent cohort of the Workforce VDC program, this young woman continued with the program as a team steward.

> ***“So not only has VDC allowed our female students to develop their leadership skills, but it also gives them numerous opportunities to meet and be directly mentored by industry professionals who are also female. In the end, one of the greatest benefits I've found with VDC is that it shatters the 'glass ceiling' and shows our female students what opportunities are open to them in the future. What other High School class can come close to offering this? In a decade of teaching, I have yet to find one.”***

It is the experience of these young women that we draw from for a discussion on women in the construction education system.

Through teaching numerous construction courses over the past decade, it is our observation that the young women in the Workforce VDC showed greater sensitivity and readily accepted social issues of justice and the environment as problem topics. We observed a similar trend in Dr. Fruchter's Architectural-Engineering- Construction Global Teamwork course—safety is often raised unprompted as a topic by women and in particular students from universities in Nordic countries, this is regardless of a student's country of origin outside the Nordic world.

These three young women will each continue in the construction industry on a pathway that will increase the participation of women in the constructionindustry.

6 Lived experience and theory development

The authors contribute a feminist positive pathway to the virtual design and construction theory through three theoretical modifications: (1) recognizing the existence of a barrier for female participation, (2) a novel model for creating a feminized space, and (3) a framework for documented effects of increased female inclusion.

As Russo (2018) saw with craftswomen in India, globally, a marketed image kept them in a marginalized place as inferior women; however, these women were more than that image and while globally the perceptions of the elites constrained these women's image, there was a freedom in gendered space locally in which these women exercised their power in a way quite different than their global image would suggest.

While we see a potential of women in AS-CTE to reduce inequality, there is a concern about a historical fact that as women enter a field they can come to dominate it (PBS 2020). Our goal is not a purely female cohort, we are looking for a co-ed cohort. The mixture of that cohort is not our concern, as United States Supreme Court Justice Ruth Bader Ginsberg said at a Stanford talk, there were more men than women in academics, so why not have a time when there are more women than men in academics! Using our education platform as a pragmatic situation, of the teachers that are the subject of this paper not one of them is a woman—we are not concerned about an imminent feminization ofeducation.

A concern that the authors are acutely aware of is that the young women in the Workforce VDC program could fall victim to the 'acting white' label. This is a tacit concept understood by our students and does not require a citation. However, there is much research on higher education being traditionally white spaces. Post-secondary CTE is not immune to this phenomenon. Because we are in the San José region, this term takes on a social class dimension that transcends race andbecomes more of a label ofselling out your working-class peers to act middle class. Many students believe secondary education spaces are ‘white spaces’ therefore, they do not belong. As educators we have collectively observed students who attempt to transcend these barriers and partake in these spaces, only to become further isolated from their communities. As a result, many students end up in ‘white spaces’ which are culturally, and physically far from their communities which further exacerbate their isolation. To make matters worse, often upon return to their communities, they are stuck with a label of privilege that they may or may not actualize. This label is powerful and can divide peers instantly and permanently. Fortunately, we did not observe accusations of acting white. However, it is possible we were not sufficiently calibrated to detect this phenomenon. We have also considered that because we are a workforce construction program, this may not fit despite an alignment with education and symbols of prestige like Stanford University. Perhaps we have successfully bridged the gap between traditionally blue- collar and ‘white’ collar spaces. If not, this is the hope for future iterations of our curricula of gender equity and social justice.

Despite observing success in a novel education platform that supports young women, once these women continue in the construction industry, they will potentially find systemic issues that present a new set of challenges. Are trades a viable pathway for women? A discussion that developed during feedback with dedicated academics of feminism is if women choose to join the trades or if systemic barriers prevent women from joining and retaining in the trades. To address this question, a fifth-term union apprentice in the pipe trades shared her experiences (apprentices have five terms of education before turning out as a journey skill level). In her experience as a tradeswoman within the San José metropolitan region, she has not experienced gender discrimination—her experience is the opposite. That said, she hears first-hand from tradeswoman in other metropolitan regions around the country who experience severe gender discrimination.

If her gender- neutral experience is representative of the region, then the young women in the Workforce VDC program should find a clear gender-neutral pathway from secondary education, through post-secondary pre- apprenticeship, and on to apprenticeship (while outside the scope of this paper we heard feedback that a transgender individual found difficulty). The issues that slow the advancement-in and even abandonment-of the trades are the same that plague mothers in academia (termed MIA). There are numerous graduate student parent alliances that address these well understood gendered issues, at the core, it revolves around access to childcare, living wages, and dependent healthcare (Stanford 2017). For the 4 percent of households that are led by a single mother, these issues are dire—particularly given that over half live below the California Self- Sufficiency Standard (Office of Women's Policy 2018). As the workforce in this paper is unionized, therefore, healthcare and wages are not an issue as union pay is equal and quality healthcare is provided, however, childcare is an open issue. Three specific situations were given as case examples.

- On-call childcare when a work shift is unexpectedly extended from eight hours to ten, twelve, even sixteen hours or more.
- Family leave during birth and maintaining a priority on the out-of-work list despite a break in work.
- Childcare during weekly evening apprenticeship classes and monthly general membership meetings.

In the United States, unlike some global regions, childcare is a private for-profit industry. As such, if the market forces do not find a suitable profit in your specific situation, you can find zero available childcare options. In the study region, 47 percent of children have access to high quality subsidized preschool (Office of Women's Policy 2018). Universal childcare is a topic of discussion amongst some public policymakers, however, to date, it is a discussion and not a reality. It is our impression that as collective bargaining agreements include gender- neutral benefits that childcare will find a solution. Further, we look towards a future that includes universal childcare.

We observed a possible corroboration of Correll's lab findings given the introduction of our feminist positive pathway to Correll’s gender-neutral pathway and then saw the expected disruption that Correll observed in gender biases, our validation is within construction workforce education pathways.

7 Limitations and recommendations

To explore issues with social justice we introduced specific situations in the experiment platform. However, those are things not normally seen in the industry nor at a top university. We assume this feminization of the construction industry is representative of a future gender-neutral construction industry. A limitation to generalization was the sample size. Also, given the unique setting in California, it is difficult to generalize the findings.

We recommend educators adopt the feminized gender-inclusive VDC curriculum guided by PBL. An increase in young women entering the energy sector trades would likely bring social change to the worksite.

In particular, there are questions relating to childcare public policies and provisions in agreements through social public policy such as those being developed by David Campos' County offices of social justice (Bay Area Reporter 2018). The union training centers are an important college pathway that both develop the next generation of a skilled workforce, as well as the next generation of union leadership; we see an expanded role of the union education system in the oversight of the workforce education pathways—in Fig. 12 a panel of union leaders attend a Workforce VDC event.

The authors recommend continued research into the role of a feminist positive pathway in a cultural change towards a greater focus on safety, environment, and society.

8 Acknowledgments

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Appendix

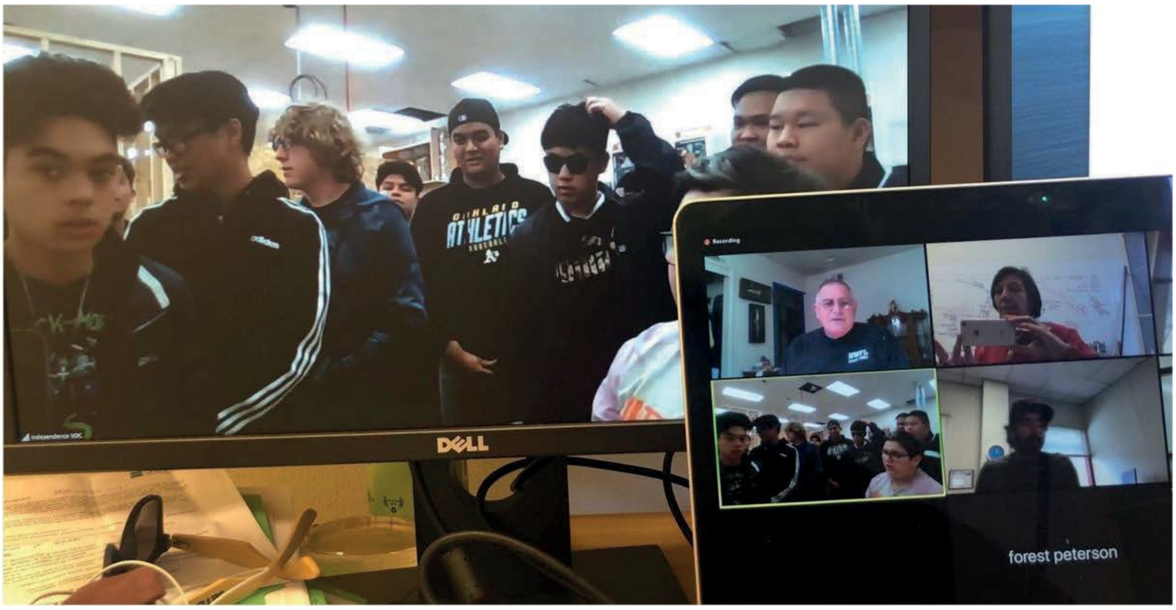

Figure 1: typical secondary construction program with a predominantly male cohort; the image is of a VDC team preparing to present.

Figure 3: The 2020 cohort of young women gather around an international Stanford construction engineering doctoral student to share insights into being women in the construction industry.

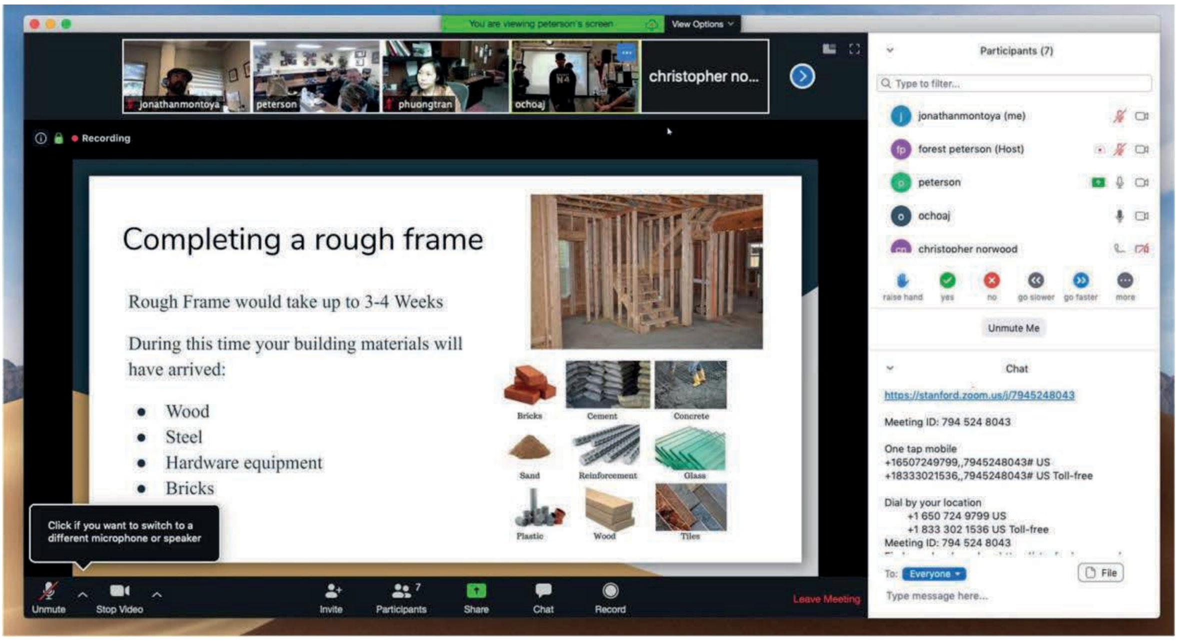

Figure 4: An example of the virtual call format with a mentor panel of practitioners pulled from the collaborating community of practitioners.

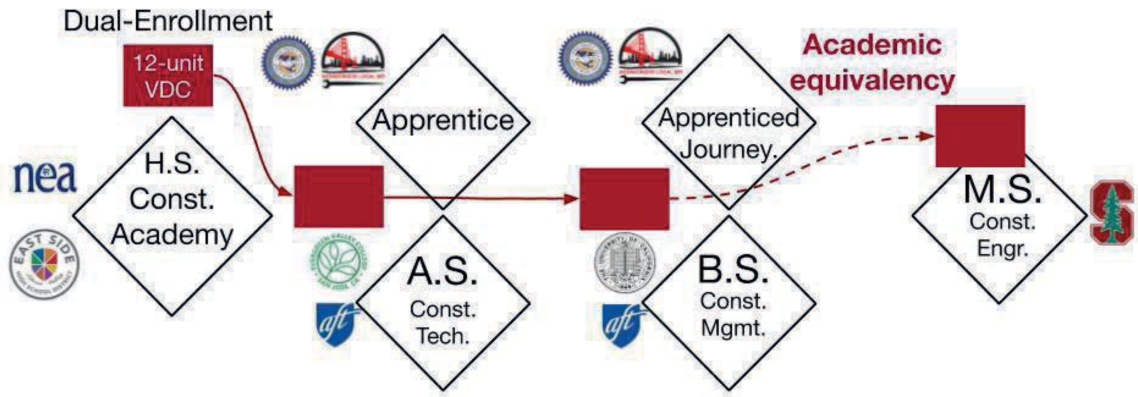

Figure 5: Comparable college pathways through trades and traditional college preparatory.

Figure 6: At the March Dryrun presentations, two months prior to final presentations, students are looking at their presentation slides.

Figure 7: At the March Dryrun, mentor feedback on presentation skills and construction technical details.

Figure 8: After two more months of project development and virtual mentoring calls, the students return for a May final presentation. The presentation, social, and technical skills are now equivalent to the university level.

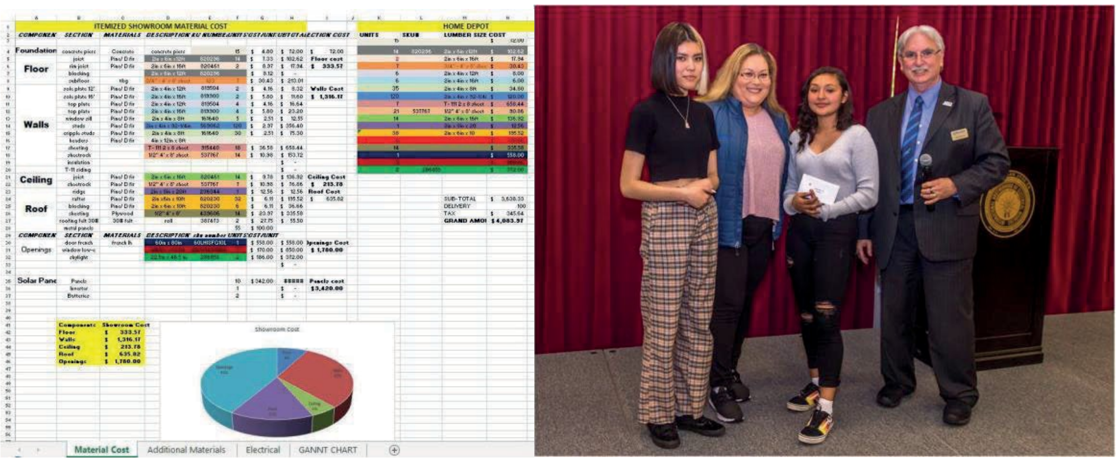

Figure 9: The cost estimating spreadsheet developed together by the two young women. They received a construction skills fair award for their project; they are flanked by a business leader and a labor union representative—the event is held at a building trades labor union hall (IBEW).

Figure 10: Young women have been quick to embrace social justice topics, such as homelessness. That is key to the Workforce VDC program. Students propose and develop solutions using approaches and technology tools that are used for traditional construction problems, therefore, learning those skills through an alternative narrative.

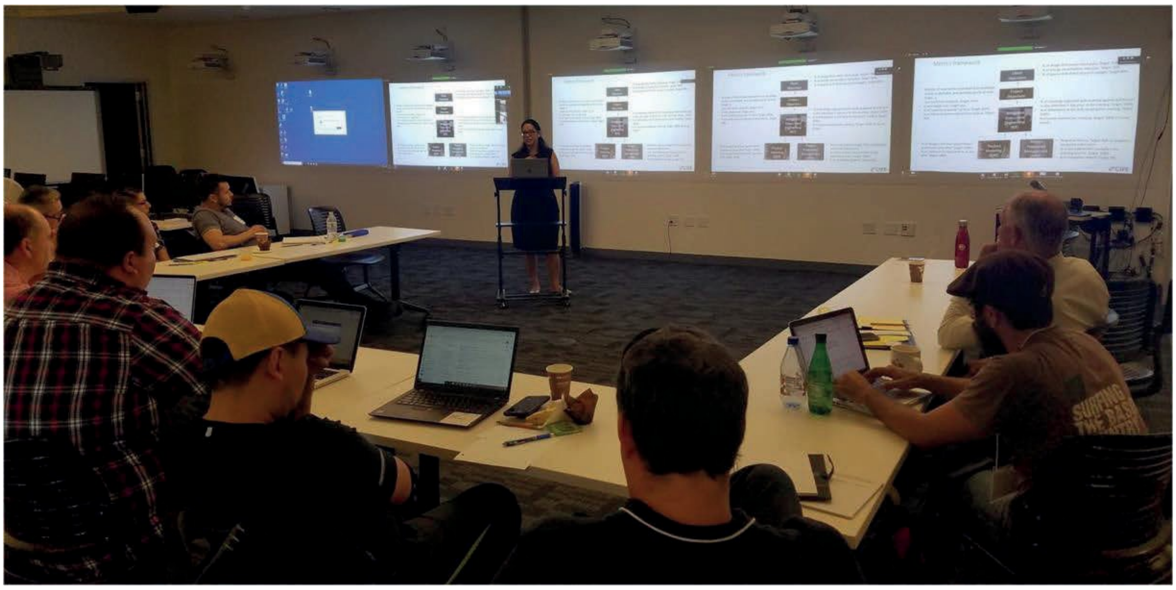

Figure 11: The teaching cohort is predominantly male; the only woman is the doctoral student lecturing on construction theory.

Figure 12: Growing a network of education leaders includes the labor union apprenticeship education system; we have good progress, seven current or recently retired union labor leaders and union apprenticeship educators attended the final presentations (building trades leadership, pipe trades, pipe trades education, ironworkers, carpenters education, and service workers); standing in the back is the president of the Stanford campus higher education workers—the executive director of the higher education workers is giving a keynote opening guest lecture.

An Interdisciplinary Biotechnology Project -- Experiences with a change to PBL

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Abstract

Studying at the Hamburg University of Applied Sciences (HAW Hamburg) focusses on the development of theoretical and practical engineering competences on a scientific level. Since its foundation fifty years ago, didactic concepts have mostly followed standard teaching formats: lectures and lectures combined with various lab exercises in small groups. For Bachelor engineering programmes like biotechnology, 90 % of the first semester contains modules like mathematics, physics, chemistry, biology, and informatics. They introduce essential basic concepts, but students often fail to recognise the relevance and connectivity of these topics for their intrinsic field of interest, which are biotechnological processes. To tackle these problems, a seminar with a weekly time slot combined with a one-day biotechnology lab session was introduced ten years ago as a voluntary module in the first semester. After five years, we changed the didactic concept to Project-based learning (PBL). Today, we can look back over five years of experience with both approaches: the old and the new.

This paper explains the change and gives a description of the change process and reflects on the pros and cons of these changes. It summarises the experiences from the students' as well as from the staffs' perspective. It discusses special problems introducing an alternative learning concept within a university with other teaching traditions and different teaching methods that run in parallel modules. We chart the iteration of improvements of this project as a nucleus for curricular development of the first year of engineering programmes and give an outlook for further developments of the interdisciplinary project itself and its possible integration into future curricula.

Keywords: conversion to PBL, biotechnology engineering, first year students, interdisciplinary project

Type of contribution: PBL best practice

1 Three phases of development of the Biotechnological interdisciplinary Project (BiP) module from 2010 to 2020

Engineering education at UAS (**U**niversities of **A**pplied **S**ciences) in Germany, for example at HAW Hamburg, start either directly after finishing school or after completing a vocational education in a technical field, which allows entry into higher education. Newly arrived students come from very different school backgrounds yet show a high degree of heterogeneity in terms of motivation and readiness to perform.

During the first semesters at HAW Hamburg, students usually follow teaching in classes combined with labs (for three to six hours a week). Both contain standard exercises including exercises with definitive solutions. However, students are not exposed to generic problem solving nor to larger team building. Thus, the development of students' creativity and social competences are not encouraged. Instead students' minds primarily must cope with a huge amount of technical information in the different fields of STEM (**S**cience **T**echnology **E**ngineering **M**athematics).

These environments of teaching and learning stand in a stark contrast to modern engineering working conditions, which are: mostly team based with complex job tasks, unknown solutions, multiple ways to reach goals and, which require a high degree of creativity. One goal of higher education is to effectively prepare students in the best possible way to enter the job market. Employability is a high priority, especially at UAS. Thus, thoughts about changing the didactical concept are apparently reasonable (Jensen et al. 2020).

1.1 Interdisciplinary Learning Setting

When some highly motivated colleagues met to improve the Bologna Process at the faculty of Life Sciences in 2009 and to start a process of change, an exciting development began; it was called BBB ("BBB" = **B**etter **B**ologna for **B**ergedorf). In 2010, seven teachers created an interdisciplinary project, called BiP (**B**iotechnological **i**nterdisciplinary **P**roject). They taught one another in their own disciplines such as maths, computer science, physics, chemistry, or bioprocess engineering by explaining questions from their particular perspective concerning "Batch cultivation of *Escherichia coli*" By learning from colleagues of different disciplines, teachers set the basics for interdisciplinary teaching in the following semester.

Figure 1: Phase 2010 to 2014: Interdisciplinary learning setting

What was particular about this approach was its:

1. Interdisciplinary work
2. Focuss on the 1st semester of a STEM programme
3. Bottom-up approach
4. Team teaching

It should be emphasised the unique interdisciplinary approach started with 1st semester students in the bachelor biotechnology programme whereas normally biotechnology topics wouldn't be introduced until later in the curriculum – at the earliest in the 2nd year. This often led in the classical didactical settings to a relevant loss of motivation during the first semester - which in numerous cases was followed by drop-outs.

One semester later, the module "Biotechnological interdisciplinary Project (BiP)" was offered to students for the first time (see figure 1). It included practical work once in a term in the lab of bioprocess engineering and in a PC-room (see figure 2 "Interdisciplinary Learning Setting"). The practical work in the interdisciplinary project took place in some labs of process engineering where students normally would not work until they were in their 4th semester.

Main parts of BiP stayed "classical", for example, lectures with strong elements of team teaching, the type of examination was to create a poster, which had to be presented to all, teachers as fellows. Therefore, another colleague for communication and presentation skills was asked to join the team.

A maximum of fifteen students could participate in the project. Students formed three groups of five. The groups were formed randomly due to the fact that they did not really know each other.

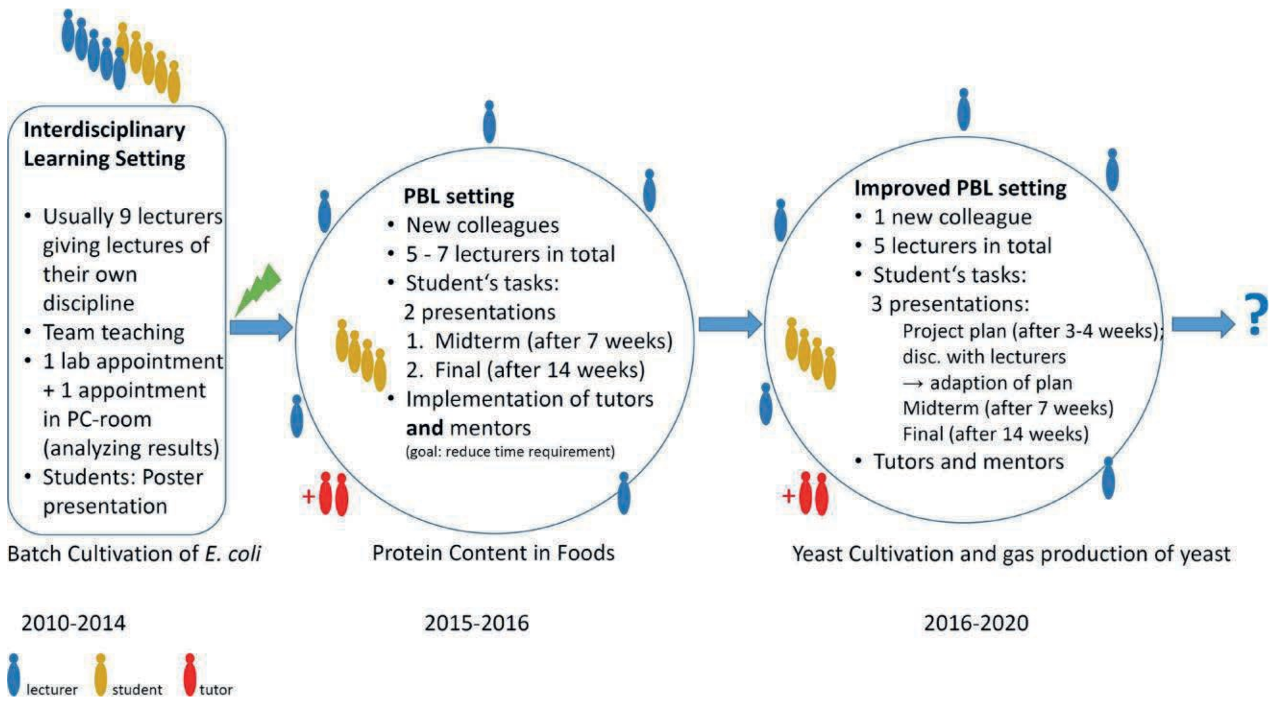

Figure 2: Development of the BiP module from 2010 to 2020

This new interdisciplinary project ran for nearly five years and teachers became aware that first semester students had the ability to do small but relevant lab experiments at a much earlier point in their education. This was a hurdle for many other projects as well! Students were able to draw conclusions.

Normally biotechnology topics are only introduced in the 2nd year of the bachelor curriculum but student motivation for taking the programme biotechnology is mainly triggered by working in laboratories. So students appreciated this module for two reasons. Firstly, because of the type of learning that was taking place, despite a relatively high workload and secondly, due to the subject content. Major points mentioned regularly by students were the benefit of being able to work in a laboratory and the exceptionally good supervisory relationship. On the other hand, students criticised the high workload and partially the high demands of lecturers.

With regard to the students, teachers noticed the separation of those who wanted to be challenged to a maximum in their self-responsibility and those who appeared to be unable to change their attitude from seeing learning as simple consumption and not as an active and independent process.

One important problem on the part of the nine teachers was that they were only given two teaching hours, which did not accurately reflect the time they had put into the project. In contrast, all the hours spent on the team teaching concept actually were held in the teachers' free time and thus not awarded. Furthermore, some teachers realised and reflected on the partially big differences concerning the teaching methods that the project required, the long-term engagement and especially the attitude towards students in general. Consequently, emotional distress arose and, as a result, the BiP was stopped temporarily during summer 2014.

1.2 PBL Setting

PBL was not, and is still not the standard teaching methodology at the HAW Hamburg. Therefore, neither teachers nor students have gained much experience in the PBL approach. All other courses were taught with a different pedagogical concept of small class instructions which is known in German as, "Seminaristischer Unterricht"). Nevertheless, in the biotechnology bachelor program at least one practical training took place per semester (≥ 2 hours per week). The high percentage of practical training signifies one of the main strengths of this programme.

The university was moving towards a Constructive alignment model of teaching and learning, which focussed on constructive alignment and the matching of lectures and examinations to learning outcomes. In 2014, a colleague introduced his experiences of PBL from another university of technology where he implemented a didactic centre after a visit to Aalborg in 2012. Other lecturers participated in a workshop given by Anette Kolmos at the summer school of the Alfred Toepfer Stiftung F.V.S., Hamburg (2011) and a workshop dealing with PBL was given by Theo Middelkoop at the HAW Hamburg (2012). That is why within the group of teachers had some awareness of PBL methods.

In the beginning of the change process from an interdisciplinary project to a PBL project, different possibilities of how to put PBL into practice were discussed. Finally, the group of lecturers decided not to follow the Problem-based learning method invented at Maastricht University (Albanese & Mitchell 1993). Nevertheless, to focus on a PBL setting by presenting an exemplary, theoretically designed case study, adapted from the Aalborg PBL model (Aalborg Universitet 2015) but not the standardised seven jump process ofMaastricht.

Since the aim was to work with first-year students and complete the project in the same semester, the lecturers felt that too much time was being spent during the 2nd jump "identify the problem". Therefore, the problem was already defined roughly as "paper case". Even in this setting, students spent enormous amounts of time discussing things but not focussing on how to come to action (figure 2 "PBLsetting").

Some aspects of connecting interdisciplinary work with PBL as, for example described in (Jensen at al. 2019) - but from the perspective of a development from the first to the latter - are given in the following list.

After the suspension of the project in 2014 lecturers met to redefine BiP. The discussion process took place on several levels. Because the laboratory manager had left the project, first of all new practical cases were needed which could fit into current lab practices. Secondly, the group of lecturers discussed why the project failed and what needed to be changed in the learning setting to create a successful new project.

A brainstorming process collected the aims of the new setting:

1. understand cross linkages between different disciplines
2. create positive experience in order to enhance orientation of students
3. increase the original motivation of students
4. lower the drop-out rate
5. transmit enthusiasm to students
6. gain new and deep insights concerning relevant research questions
7. have fun by learning and teaching

To find adapted cases lecturers discussed which ones were suitable tor first semester students, and could be done in the chemistry labs instead of the lab of bioprocess engineering. At first, the proposed “migration of tin (Sn) from the tin can to the containing pineapple” was chosen from the set of proposals. However, during the application in the lab by one lecturer some technical problems occurred. Particularly regarding the question of laboratory safety for first semester students working with a flame absorption spectrometer. Furthermore, the time during the term was quite limited; there were only two to three lab days are possible.

Figure 3: PBL setting. Lecturer as mentor

In the next phase, lecturers decided to define case studies concerning the protein content of food (Figure 2 “PBL setting”). The protein content could be determined quite easily by the Biuret reaction and a photometric analysis at least for some foods. Important advantages were the non-toxicity of the relevant chemicals and the simplicity of the execution of the test. During in the process the difficulty became obvious. The question was how to find simple cases which forced students to deal with basic techniques to solve thechallenges.

At the beginning of 2015 teachers ran the project as ‘first level testers’ and developed an experimental protocol. An adapted case study was handed out to four students. These students worked out their project successfully and presented the results to the lecturers. After a reflection process within the group of lecturers, they decided to start a "new" Biotechnology interdisciplinary project for students in the following term.

BiP was announced in class and at the kick-off a maximum of four groups of four students started. Each group received its own individual PBL case and had to plan the project independently. The time management was in the hands of the students and was completely separated from the normal semester plan.

For the first time tutors (see red figures in Figure 2), were organised to support students during the group building process as well as during the search and lab work in order to lower the fear threshold towards lecturers. Additionally, each of the four project teams were supported by a mentor from the group of lecturers who accompanied the group during the semester (figure 3). The first meeting of the mentor with the project was organised by the lecturer. At all further meetings, the initiative had to be taken by the students. This system became the norm and the pedagogical setting is still practised now.

An additional option of the project groups was the possibility of arranging appointments with "experts" from the teaching team, depending on the progress of the project and any questions that arose. For example, the mathematician in the team could be consulted when it was necessary to approximate measurement data by a function. Unfortunately, this option was rarely used by students. The inhibition threshold for 1st semester students to arrange consultation appointments with professors seemed to be very high.

Students had to present their ideas and results in two presentations as a type of examination: 1. a Midterm presentation (after 7 weeks), and 2. a final presentation (after 14 weeks) to classmates and teachers as well.

1.3 Improved PBL Setting

During the BiP runs in 2015 and 2016 it was repeatedly observed that students took a very long time to work together effectively as a group and set up a work plan. In order to overcome this weak point in the pedagogical framework, the number of milestones was increased from two to three (figure 2 "Improved PBL setting"): These were the very early discussion of the project plan after approximately three weeks, the mid-term presentation and the final presentation at the end of the semester. Students were completely free to choose the form of presentation of their project. To date, in addition to the classic slide presentation and poster presentations, there was a video, a cooking show and a storyteller. After each talk, presenters were given detailed feedback from the teachers, tutors and other fellow students.

However, the technical ideas changed to more biotechnologically applied case studies. Realization took place by the readiness of a new colleague in the team as head of the lab of bioprocess automation. Once again, teachers and tutors worked out two different experimental protocols and case studies concerning the fermentation of baker's yeast. One study focussed on the CO_2-production during fermentation in a liquid culture and in a yeast dough whereas the other case study required students to come up with an exponential growth of *Saccharomyces cerevisiae* (baker's yeast) during a cultivation, an experimental work in the lab of bioprocess automation. Both case studies worked within labs (figure 2) but without the use of any potentially harmful substances. This was an important prerequisite condition for first semester students.

Figure 4: Improved PBL setting. Students in the laboratory of physics analysing measurement data

Today these two scenarios are given to students each semester. Most students prefer the case study with the cultivation of *Saccharomyces cerevisiae* rather than the gas production one. Lecturers suspect the reasons for this response may be because the announcement included photos of the lab of bioprocess automation. In contrast the announcement and accompanying photos of a yeast dough was not seen as attractive. One student explained that they preferred the other case study for this reason. As a result, lecturers decide to modify the introductory part of the project by stressing the research aspect of CO_2-production during fermentation and the link to biotechnological processes and the possibility of working in the lab of inorganic chemistry (figure 6) and in the lab of food technology as well as by showing lab photographs instead of yeast dough. In summary, BiP continues to be a project undergoing change.

As a consequence of different case studies, the project groups had access to very different laboratories to carry out their experiments from another lab of bioprocess automation, of inorganic chemistry, of food technology and of bioprocess automation (figure 6). Appointments had to be coordinated independently by the students with the responsible laboratory managers. Students were also responsible for following the necessary safety instructions and wearing protective equipment such as lab coats and safety goggles. During the laboratory work, the project teams were accompanied by student tutors who were well versed in the respective laboratories. One challenge was that the tutors were not supposed to provide the project groups with "solutions", but rather to accompany them on the way to a possible solution. The best way to achieve this goal was if the tutors had participated in BiP in the past. The tutors had a very good relationship with the project teams and could also give them tips on teambuilding and time management.

In addition, sometimes an excursion would be organised to different companies working in biotechnology in order to stress the professional relevance of the students work.

2 Observations and results of the changed PBL process

So far, 207 students have participated in BiP (Table 1). Of these, 22 students dropped out of BiP prematurely corresponding to 11 %. It is a great challenge for the remaining BiP students to achieve a good result as a group despite the drop-out of individual students.

Table 1: BiP Tasks and Number of Participants

Semester	Number of Participants	Students dropped out	Task
Summer 2010			Test without students, only lecturer Batch Cultivation of *Escherichia coli*
Winter 2010-2011	15	?	Batch Cultivation of *Escherichia coli*
Summer 2011	15	?	
Winter 2011 - 2012	15	2	
Summer 2012	15	4	
Winter 2012 - 2013	10	0	
Summer 2013			BiP cancelled (less than 10 participants)
Winter 2013 - 2014	15	2	Batch Cultivation of *Escherichia coli*
Summer 2014			BiP cancelled (less than 10 participants)
Winter 2014 - 2015			Discussion of lecturers concerning change to PBL
Summer 2015	4	0	Test with 4 students Proteins in Food Products
Winter 2015 - 2016	16	0	Proteins in Food Products
Summer 2016	16	0	Yeast: Gas Production and Cultivation
Winter 2016 - 2017	10	1	
Summer 2017	16	5	
Winter 2017 - 2018	10	2	
Summer 2018	11	0	
Winter 2018 - 2019	13	1	
Summer 2019	16	4	
Winter 2019 - 2020	10	1	
Summer 2020			BiP cancelled due to Corona

2.1 Questionnaire

In 2016 and 2017, students were asked for their feedback on BiP. In addition to the oral feedback (2.2), which the students are always asked to give, a structured questionnaire was used in 2016 and 2017 after the change to PBL was made. This questionnaire was divided into two parts: Part 1 focussed on competence evaluation as self-assessment (table 2), part 2 consisted of open questions on satisfaction, important experiences, challenges, advantages and disadvantages of project-oriented learning, changes in the importance of individual basic subjects and the students' willingness to recommend BiP.

Results of part 1 of the questionnaire showed a higher number of entries (85 %) for (completely) true (green line, figure 5) than for not true (at all) for all skills (yellow and red line, figure 5). Regardless of the question and the group surveyed, "true" was ticked most often (light green, 56 %), showing most of the students achieved a self-perceived growth in different competences by taking BiP.

In general, the students of 2017 voted more critically than those of 2016, especially regarding cooperation competence, but in 2017, nobody agreed with "not true at all" (red line) and only 27 % of entries was accounted for as "not true" (yellow line). The most critical entries seemed to be about self-competence and cooperation competence. In contrast, the biggest increase of competences took place in the professional competence ("I feel able to enter into a typical question of Biotechnology"), although the teachers remained sceptical about the validity of this remark.

Table 2: Competences and questions asked by a questionnaire after participation in BiP

Competence	Question to tick with a cross on a 4-step-scale (completely true, true, not true, not true at all)	Shortform of ques-tions of Figure 5
Professional competences	Due to BiP I feel able to enter into a typical question of Biotechnology.	Discuss Biotechnology
Methodical competences	Due to BiP I can search for information more effectively.	Search information
Self competences	After my participation in BiP I can motivate myself better to work on a task, even if I do not enjoy it at first.	Motivate myself
Presentation competences	Because of our presentations at the midterm and at the end, I can better orient a presentation to the audience.	Align presentations
Cooperation competences	By participating in the group, I now adhere better to the agreements within a group.	Adhere to Agree-ments
Communication competences	Due to my participation in BIP, I would better be able to get to the point of what I am saying.	Come to the point

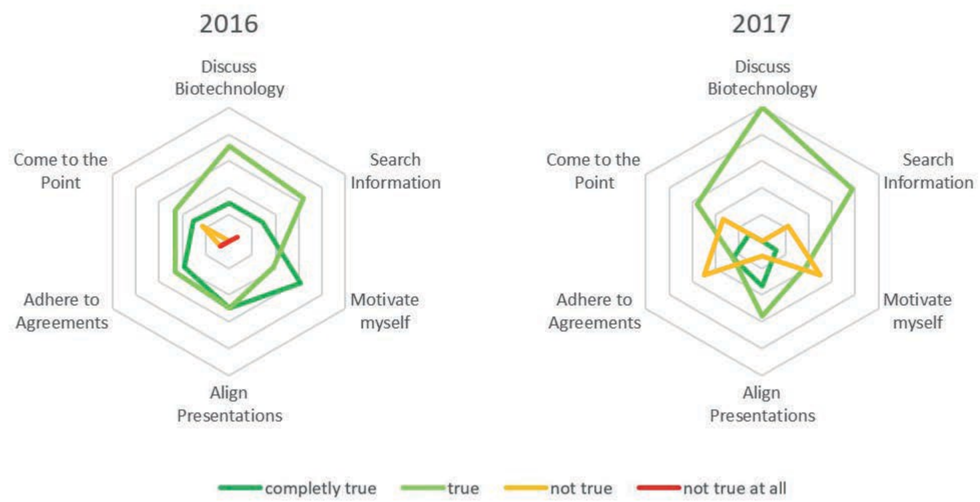

Figure 5: Results of the questionnaire (table 2) regarding competence evaluation as self-assessment. Agreement in % of respondents in 2016 (left, n = 14) and 2017 (right, n = 9).

Concerning part 2 of the questionnaire, students mainly mentioned that the challenges of BiP were time management, how to start a project, how to work in a team and coping with failure in the lab during research work, stressing the importance of self-competence and cooperation competence again. In summary, the results on PBL-oriented learning show the students' appreciation of their own gains in soft skills.

2.2 Oral Feedbacks

Regarding oral feedback, the extent of the comments varied considerably, and the results were largely consistent with the answers to the open questions in part 2 of the questionnaire. On the positive side, students mentioned in particular, the lab work and excellent mentoring/support/care by tutors and lecturers.

The students' main criticism was not getting enough credit points for the amount of time they had invested. The expenditure was estimated as too high, respectively. On the contrary, in the last winter term, students were required to count the hours they spent on BiP, resulting in an average of 86.75 hours per student. Corresponding to 2.5 credit points and 75 hours, the workload was exceeded by 16 % in average, not to mention one group reaching exactly 75 hours. Anyway, all students reported the participation in BiP as an enriching experience.

2.3 Students success rates

A comparison of the students participating in BiP with those who did not participate is still ongoing. Indicators like credit points per semester, credit points after the 4th semester, graduation, marks (especially on projects and on the bachelor thesis), would be useful. Due to the necessary time requirement, results will be shown at the conference presentation.

3 Reflection

In the beginning, no credit points were given to the students, i.e. participation in BiP was based only on free will. The same applied to lecturers as well as for students. Lecturers were highly motivated, but keeping the motivation going for year after year was challenging for some. Therefore, most of them left the team of lecturers.

Since 2015 (new examination rules), standard 2.5 credit points are awarded for BiP. But still a lot of work is needed to deal with group dynamics and dropouts. Partially, students split up according to major disagreements concerning motivation, reliability, commitment, and tolerance of frustration, which is another important factor. In total, communication may be the most important challenge – in all aspects: teacher-student, student-student, teacher-tutor, tutor-student, tutor-tutor and last but not least teacher-teacher. For example, some groups took a lot of time just to make a first appointment correlated to communication by social media instead of face-to-face-speaking during the normal lessons.

All lecturers were aware of the high heterogeneity of students. Sometimes it was difficult to supervise teams with participants without any experiences and talent for project management. In contrast, other students were well prepared because they had learned about project work in school or during their vocational training. If inside a team nobody was able to establish structures to define a committed plan, the learning process was very slow, especially if students were not able to request help from a tutor or a lecturer. At this point, the importance of finding suitable tutors became obvious, i.e. tutors who could keep an eye on the group and at the same time keep the balance between allowing the group to develop on their own and intervening by asking questions.

Regarding the different biotechnological cases, problems made the work less attractive for some teachers, but they were not that easy to change as they had to have a practical impact, not contain harmful substances and be handled with basic competences in a chemical or biotechnological lab.

Lecturers realised that every term some high potential students did not choose BiP because they felt the necessary investment in time, expenditure and energy was simply not worth it. In the future, it would be fantastic if all participants could gain from the experience, especially those students.

3.1 Positive Outcomes

In the first step of the interdisciplinary project, the awareness of the teachers involved of the (technical) needs of others really increased. Hence, team teaching was carried out in various constellations of people. Coordination processes required a great deal of time, but led to an improved linkage between the basic courses beyond the project. The special characteristic was the opening of one's own teaching and the critical questioning that accompanied that. In this way recognition of the other professional cultures took place as well as communication with other colleagues from the same discipline. In fact, BiP has triggered feedback processes among teachers with regard to their own teaching and in some cases has also had an impact on teaching beyond BiP (coordination of definitions, approach, and use of technical terms). Fundamental questions arose, e.g. how can one show that something is as it is in a scientific way? How does research actually work? As a result, teachers discuss curricula in much greater depth; working on making sense of it. This meant spending more time on their practice, but on the other hand that is the point of deeper enrichment and development for teachers (the"uh-huh moments!").

A great deal of trust was built up within the group of lecturers and was constantly being developed. This was also advantageous for the students because the teachers could make each other aware of special features. Starting with the interdisciplinary project, the students were forced to give presentations. Afterwards they could watch the teachers giving feedback. In the PBL setting the students were also required to give their fellow students feedback. The more the students were encouraged to do so, the more appreciative and critical feedback was given.

3.2 Lessons learned

At every stage of the change process, it was obvious that the success depended mainly on the engagement of the lecturers. Round table discussions after each term led to a fruitful exchange. Only at this stage ideas became clearer and improvements could start e.g. which chemical processes are relevant behind the ostensible baking process and how to get students to certain findings without telling them directly.

Lecturers observed various dynamics within the student groups and had to respond proactively. In the beginning of the PBL setting, students needed far too much time to draw up a concrete plan, arrange appointments with lecturers and fix laboratory appointments. Therefore, the lecturers decided to introduce another early milestone three to four weeks after having started: Students had to submit a written project plan and discuss it with the teachers. This was an example of the balance between degrees of freedom and the tight leash inside a PBL setting.

From a bird's eye, starting as submarine inside an organisation driven by other forces may be okay, if you have a powerful teaching team with members, who know what they want. Changing the mind-set of students is not possible if the majority of exams are driving them to completely different foci. Problem of pure memorization (lowest tax level 1: knowledge) without comprehension (level 2) is the main working place for the first semester students, but PBL already brings much higher levels (level 4: analysis / level 5: synthesis) into play. PBL may be challenging and progressive for motivated challenge takers, but may be too much for those students, who have difficulties with the basics.

3.3 Outlook

BiP has changed several times in the past and will continue to change in the future. Finding more generic problems, which are change-friendly, would make BiP even more interesting for students and for teachers. So far, no explicit learning outcome has been formulated for BiP, even if it is implicitly present in the group of teachers. HAW Hamburg is committed to competence orientation. Therefore, the group of teachers involved will need to take the time to find the missing piece of the jigsaw at short notice. The evaluation of student feedback should be raised to standard every semester. Furthermore, the started evaluation of the effect of BiP on test parameters must be continued. BiP could serve as a nucleus for the upcoming revision of the curriculum, especially in the bachelor program of biotechnology. Here a group of enthusiastic and resourceful teachers is working together, who are always asking themselves questions about what constitutes good teaching.

In summary, it is not always evident to find an appropriate case, which is linked with relevant analysis in a lab because finding time slots besides the normal teaching activities is quite ambitious. Secondly, safety aspects have to be taken into account in lab work. In general, the analysing techniques should be of lower professional requirement and chemical reactions must be absolutely clear.

More important than the cases might be a well complementary team (both professionally and personally) of teachers, who are highly motivated, self-critical and at the same time assertive. Come and see! We invite you to share our experiences at Hamburg and to meet our colleagues and visit the labs where the process first started.

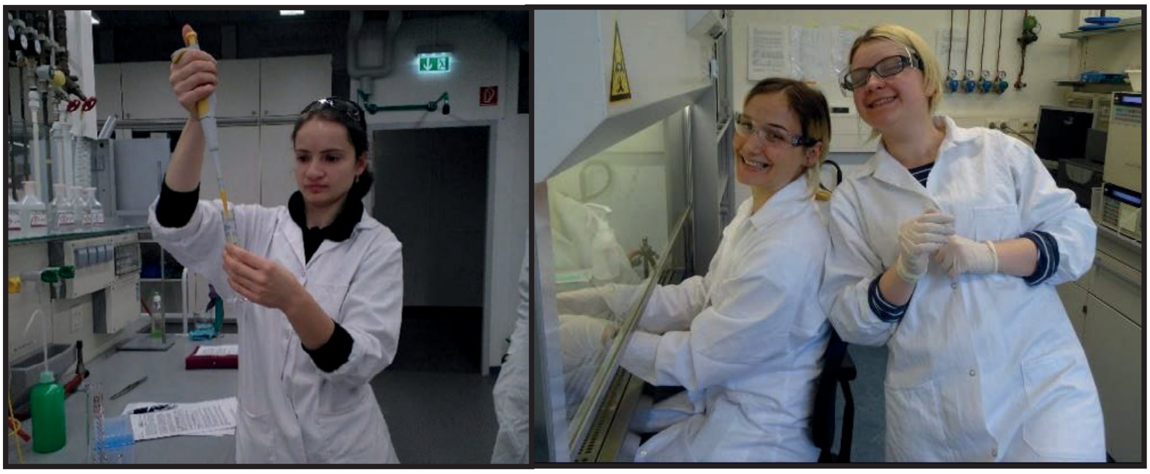

Figure 6: Impressions from the labs of inorganic chemistry and bioprocess automation

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Curriculum Design

Integrating two core Biomedical Engineering courses through a project-based learning approach: A framework for teaching student-centered comprehensive engineering design

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Abstract

Industry stakeholders are currently looking for graduates who can easily adapt to the rapid society changes that we are facing today. Engineering classrooms, however, are usually trapped in professor-centered traditional pedagogical approaches from which such high-level competencies are challenging to develop in learners. Disruptive engineering educators have responded by modernizing the curricula with the aid of Problem-Oriented Project Based Learning (PO-PBL), which is an active pedagogical strategy where students are at the center of the learning process. This approach is therefore well-suited for training a suitable workforce with the capability of responding to the upcoming highly complex societal problems of years to come. Here, we report on the implementation of a PO-PBL approach as a framework to integrate the teaching of biomaterials design, simulation and prototyping in a practical and student-centered manner. The proposed intervention focuses on a switch from traditional protocol-based and fully guided practices to project-mediated learning where students form teams to ideate and implement solutions independently. A concurrent mixed-method research was implemented to evaluate the extent of our intervention. Quantitative data analysis strongly suggests an encouraging increase for team's performance in design, implementation and prototyping, in comparison with data from a previous cohort in the absence of active learning. Additionally, interaction maps and surveys indicate a strong causality between high performance in both technical skill and people-related competencies and the student-centered way of learning provided by the project-based framework introduced for the integrated experience. The conceptual basis of the socio-cultural vision of education was subsequently used to elucidate how theoretical concepts explain the achievement of the implemented strategy. Results presented here are promising as a framework for the integration and practical apprehension of concepts of other core courses in the Biomedical Engineering curriculum as it demonstrates a route to develop key skills in crucial engineeringcompetences.

***Keywords**:* Biomedical engineering education, active learning, problem-oriented project based learning, socio-cultural vision of education, mixed-method research.

***Type of contribution**:* PBL research or review/ conceptual paper

1 Introduction

Traditional professor-centered lecturing has been the primary classroom approach for teaching engineering students for decades. The focus of such an approach relies on the lecturer leading the learning process while the students assume a passive role where no active participation or involvement during classes is expected from their side. Despite the inherent limitations, this approach has proved successful for the training of several generations of engineering professionals who were responsible for the development of some of the most impressive technologies that have transformed the world (Uziak, 2016). Nevertheless, two significant issues around this traditional education setups have recently emerged as major concerns in modern engineering education. On the one hand, several authors have shown that the rigid teacher-centered traditional approach could exclude very talented and promising engineering students from the system, as some of their learning styles require a more active involvement (Felder, 2007; Passow & Passow, 2017; Ribas, 2009). On the other hand, the current fast pace of technology development requires the inclusion of learning and teaching approaches to assist students in the development of a core set of skills that remain relevant for the ever-evolving marketplace. As a result, industry stakeholders look for graduates who can easily adapt to the rapid society changes that we are facing today. This quite exigent marketplace has propelled an increased demand for engineers equipped with high performance in oral and writing communication skills, teamwork, critical thinking, project management skills, innovation mindset, and creativity (Passow & Passow, 2017; Pellegrino & Hilton, 2012).

Over the past few years, engineering educators have responded to the challenge of modernizing the curricula according to the current industry standards by putting forward the idea that active pedagogical approaches such as those based on Problem-Oriented Project Based Learning (PO-PBL) are well-suited for providing an appropriate framework for the development of the much-needed skills (Graham, 2010; Mahendran, 1995; Uziak, 2016). PO-PBL is an educational approach whereby a real-life problem is the core of the learning process by providing a student-centered setting in which teams are assembled to find routes to address the given problem. In this case, professors mainly play a role as facilitators for team observation, ideation, prototyping and testing. Students are requested to manage the project on their own by establishing milestones, tasks and roles, resource allocation, and deliverables along the course of the project (Kokotsaki, Menzies, & Winggins, 2016). Additionally, students need to keep a well-organized database with the essential documents supporting their progress as well as their approaches to overcome roadblocks and team issues. This record-keeping practice is aimed at developing critical knowledge management skills, which have been largely neglected in established engineering curricula. Recent studies have strongly suggested that the more the problems are in a real-life context, the more the students feel challenged, motivated and committed. Hence, learning through the development of a project could be seen as a way of organizing various simultaneous and integrated learning processes (Hernández, Ravn, & Valero, 2015). Besides developing the relevant functional expertise and technological skill, this pedagogical strategy also intends to develop people-related skills such as autonomy, critical and divergent thinking, learn to learn and problem solving, group discussions and social interactions, resource management, negotiation and conflict resolution, influencing others and exercising emotional intelligence (Zhu, Liu, Liu, Zheng, & Zhang, 2019).

As a result, PO-PBL provides an avenue for a paradigm shifting where the principal purpose of education changes from what professors delivered to what students learn. As described by Uziak (2016), some of the curricular reforms recently introduced in several undergraduate engineering programs around the globe, have mainly focused on implementing this approach through a final year capstone project. This implementation has allowed engineering graduates to be exposed to solving real-life problems; however, a relatively large number of them have expressed some discomfort in such settings. This effect can be attributed to a considerable distance in the way that problems are solved during most of the course of their studies where only one answer is correct at the end of the problem-solving process. Consequently, this study suggests that the PO-PBL approach should go beyond the typical final year or capstone project and could be introduced as a long-term strategy articulated throughout the entire curriculum to develop technical and people related skills.

The benefits of PO-PBL can be also explained under the socio-cultural vision of education described by Vygotsky (1978) and the theory of communities of practice described by Wenger (1998). The former illustrates a perspective of education in which learning is seen as a complex process product of different activities, contexts and socio-cultural factors involving the learners. The latter describes each student as a member of a community of practice who gets involved in participation (actively interacting and creating identity in the community) and reification (transforming abstract information into real artifacts) to progressively becoming an expert in ideas, values, beliefs, languages, skills and competencies. Thus, in line with these two visions, the development of a PO-PBL strategy appears as an attractive alternative to help students building significant learning by iterative and dynamic participation as well as reification during the problem-solving process. Such an active process is ultimately responsible for equipping the students with the tools to re-contextualize actions and concepts from an original situation to new defiant scenarios (van Oers, 1998). This demonstrates that PO-PBL fully aligns with the principal purpose of higher education.

2 Context

This research was conducted in two Biomedical Engineering courses at Universidad de los Andes, Bogotá - Colombia, namely Biological Transport Phenomena and Biomaterials. Both are taken as mandatory core courses by students usually undertaking the fourth or fifth semester of the program. Undergraduates meet three times a week, two for lectures and one for a hands-on laboratory practice for fifteen weeks. The number of students enrolled in the course varies from 50 to 60 every semester, with ages between 18 and 23 years old. Their performance is evaluated via written tests, homework assignments, and a semester project that is mostly conducted during the lab sessions. The core of this pedagogical intervention is focused on the semester projects as they are often very demanding and require an important time commitment to complete in time the complex team tasks needed to solve a given open-ended problem. Previous to the intervention, students of both courses showed a marked disengagement and lack of motivation during the development of the project. Additionally, they commented that the project failed to provide a connection between topics covered in class lectures and the practice, and consequently required an essential time commitment on top of the conventional protocol-based lab practices that were conducted at the time. To address these issues, professors in charge decided to implement a PO-PBL approach where instead of conducting traditional protocol-based lab practices and the semester project separately, a robust PO-PBL project would be pursued. The implementation strategy included an initial pilot with separate PO-PBL projects for each course (2018-1 and 2018-2), which was followed by a combined project for the two courses (2019-1 and 2019-2). A plan to generate better use of time was to carry out both course laboratory sessions simultaneously and thus allocate a period for the meeting of the teams and work on the project. Consequently, the change in the course focus generated a variation in the system of evaluation that reflects the more significant commitment and emphasis on the project.

This work is therefore dedicated to exploring the potential benefits of a combined PO-PBL project for two Biomedical Engineering core courses as an active pedagogical approach for the development of both, technical skill and people-related skills. Accordingly, the purpose of this document is to report on the preliminary results of the proposed pedagogical intervention. The benefits and results of this study are analyzed based on an increased performance of students in project deliverables as well as in project presentations in comparison with previous cohorts in the absence of the intervention.

3 Method

3.1 Setting

The first attempt to execute a combined PO-PBL project took place during the first semester of 2019, where a total of 65 students undertaking Biological Transport Phenomena and Biomaterials joined forces by forming teams of 4 to 5 students. Teams were asked to prototype biomaterials, both in the lab and *in silico* with the aid of a Multiphysics simulation package, to mitigate the molar incisor hypo-mineralization in children. Students followed the general guidelines of PO-PBL in order to ideate, propose and prototype designs to address the assigned problem. As the projects were developed, surveys and individual and group interviews indicated that most students were comfortable with the pedagogical innovation by demonstrating higher engagement and motivation, increased technical quality and complexity in the proposed and implemented solutions, superior practical apprehension of concepts, and better overall ratings. Despite these appealing results, during the project execution, teamwork issues started to develop and even compromised the very integrity of some teams. This was attributed to the limited exposure of students to collaborative team settings to pursue an authentic communal building of knowledge.

For the second semester of 2019, the implementation continued by deploying a PO-PBL for 66 students undertaking both courses and organized in teams for project development following the same guidelines described for the first semester. Teams were organized in teams of 4 to 7 students to tackle the elimination of granulomas that are formed upon injection of liquid silicone for cosmetic purposes. Once again, students were asked to design, simulate and prepare prototypes of biomaterials to address the problem. This time, we additionally intended to tackle the observed teamwork issues by implementing two technological web-based platforms, namely, Planner® and Tandem. These project management tools were aimed at facilitating team communication, organization, and task planning and monitoring throughout the semester. Planner® was developed by Microsoft (https://tasks.office.com/) and is a platform that facilitates the monitoring and designation of tasks for each member of a team. Accordingly, at the beginning of the semester each team developed an agenda with the aid of an experienced undergraduate research assistant, which was followed as a main route map throughout the project. Tandem was developed as an in-house pedagogical tool (tandem.uniandes.edu.co) and allowed us to assess specific and overall teamwork aspects such as co-evaluation, consolidation of team contracts, commitment and active participation, team interactions, response to emergent team conflicts, and overall health of team integrity and cohesiveness during the course of the term. Consequently, the timeline for the development of the proposed framework can be visualized in figure 1.

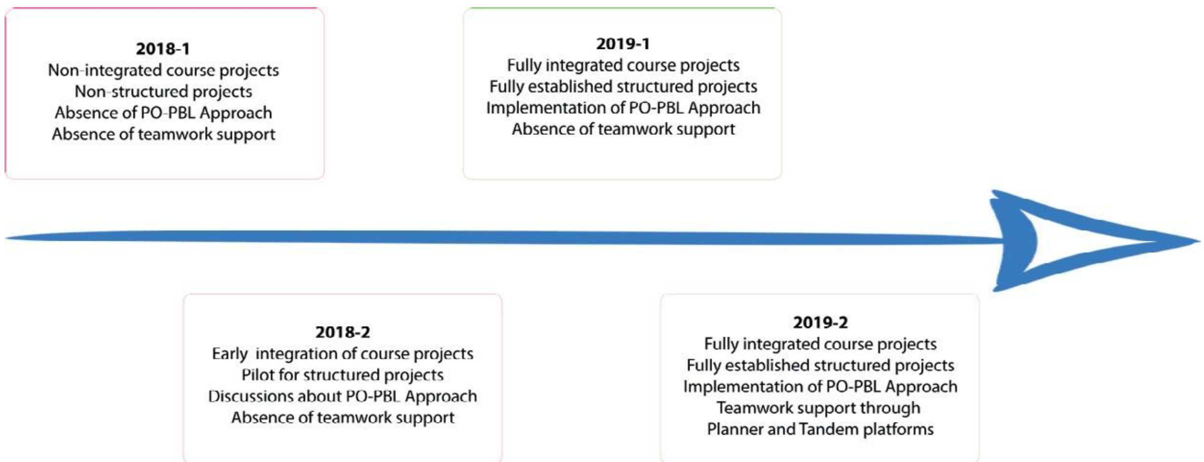


Figure 1. Development of for teaching student-centered comprehensive engineering design.

3.2 Evaluation and Data Collection

In this study, evaluation is envisioned as the systematic collection of information about the features, activities and results associated with the pedagogical intervention (Bamberger, 2012). Following the description of concurrent mixed methods by Cresswell et al. (Cresswell, 2009), the research conducted here incorporates close and open-ended strategies for data collection. Therefore, our design was planned and carried out to assess the benefits of the intervention in project performance through quantitative data, as well as build an understanding of student's experiences via qualitative analysis (i.e., Quan + qual). Consequently, qualitative data was used to explain quantitative findings as described by Tashakkori and Teddle's framework for mixed methods (Tashakkori & Teddle, 2002). Additionally, planning at the start of the research process led us to the use of specific quantitative and qualitative instruments, which were according to the fixed mixed method procedure described by Morse et al 2008.

To obtain a more complete vision about the phenomena subject of research, data associated to performance (mid-term project report, final project report, and a final project presentation) in the development of the projects was quantitatively compared between the student cohort under the full implementation during the first semester of 2019 (2019-1), and a previous student cohort with no pedagogical intervention who undertook the courses during the first semester of 2018 (2018-1). The relative impact of implementing our methodology on student's performance was obtained by directly comparing these data sets. We disregarded the 2018-2 data as early implementations were undertaken without a systematic data gathering approach. Moreover, additional data was gathered to understand the perception of students via open-question surveys and the development of interaction maps in cohort 2019-2. On the one hand, we wanted to inquire about internal thought processes and experiences of the students as interpretative visions of their own learning process via surveys (Merriam & Tisdell, 2015). On the other hand, an interaction map provides a visual description of the developed interactions between team members as they collaborate in the project. Such mapping is made by monitoring the actions of the team members in real time, and subsequently making line connections between participants. The ultimate goal was to schematically show which type of interaction was promoted at a specific moment in time. This procedure provides a general view of the behavior of teams while doing specific tasks, thereby allowing researchers to understand if the level of individuals interdependence can be correlated with the performance showed in project reports and presentations (Johnson, Ifenthaler, Pirnay-Dummer, & Spector, 2009). This approach has a limitation: the person in charge of monitoring team interactions is who decides if the interactions observed are focused or not in the development of the project. Additionally, data from professors was retrieved and used for feedback purposes, however, it was not actively included in this analysis as they play a major role in this research.

The research instruments used for data gathering provided a degree of triangulation that allowed us to establish valid conclusions by seeking convergence, corroboration and correspondence of the results obtained from the different monitoring techniques (Oliver-Hoyo & Allen, 2006). Informed consents as well as ethical committee approval were obtained for data collection in all phases of the study.

4 Results and Discussion

Figures 2a and 2b show the grades and corresponding statistical significance for the mid-term project report and final project report. Data indicates an encouraging increase in the performance of students in both deliverables after implementation as evidenced by a change in the mean of the mid-term project report grades from 3,72/5 (2018-1) to 4,44/5 (2019-1) and 4,10/5 (2019-2). Similarly, it was the case for the mean of the final project report, as grades changed from 4,14/5 to 4,58/5 and 4,29/5, respectively. The statistical significance of these findings was determined by a T-test, which was conducted assuming no equal variances in the two analyzed cohorts for both project reports. The T-test result demonstrated, with 95% of confidence level, a significant difference between the two intervened cohorts for mid-term and final project reports ($p < 0,05$). These findings provide further evidence for the notion that the student-centered PO-PBL implemented here increases motivation and engagement. This outcome could be explained by the possibility provided to students of facing a real-world challenge similar to the ones they could encounter in the practice of their profession. Additionally, the intentional rich environment (enriched by the implementation of PO-PBL practices and teamwork support) promoted throughout the course of the term seemed to have facilitated self-directed learning, which has been reported to directly influence motivation (Uziak, 2016). Furthermore, the increase in performance is most likely related to a fundamental change in the perception of project development, as professors in an intentional and systematic change, turned from a product-centered vision to a process-centered approach. This change is thought to be responsible for increasing the students´ ability to generate novel and more creative problem-solving strategies (Kokotsaki et al., 2016). Moreover, students tend to perceive this type of challenges as formative and consequently they are inclined to be more persistent and to develop resilience (Ribas, 2009).

Figure 3 shows the grade distribution for the final project presentation. In this case, the mean changed from 4,04/5 (2018-1) to 4,17/5 (2019-1) and 4,29/5 (2019-2). This finding strongly suggests that some of the deployed strategies for improving oral communication skills might be helping students prepare more impactful and robust presentations. Some of the strategies included personalized feedback from the Spanish Center of the university at the end of each presentation, mock presentations before the final one, and new rubrics with more clear standards regarding the expectations for superior presentations. Additionally, the intervention included more opportunities for interactions between students and professors throughout the course of the term. In this regard, we moved from 2 to 4 presentations during 2019. This increased number of additional activities led to higher data dispersion for 2019 (Figures 2 and 3), which suggests that some student teams are averse to team-taught environments and thereby fail to perform according to the teaching team expectations. This has encouraged us to pursue more frequent and close assessments of students' response to the planned activities such that we can adjust rapidly to the needs of each particular team. In this regard, we also found that sometimes they reached a team dissolution agreement and its members were evaluated individually, which impacts the dispersion of the data by an individual lower performance in comparison with the grades of effective teams.

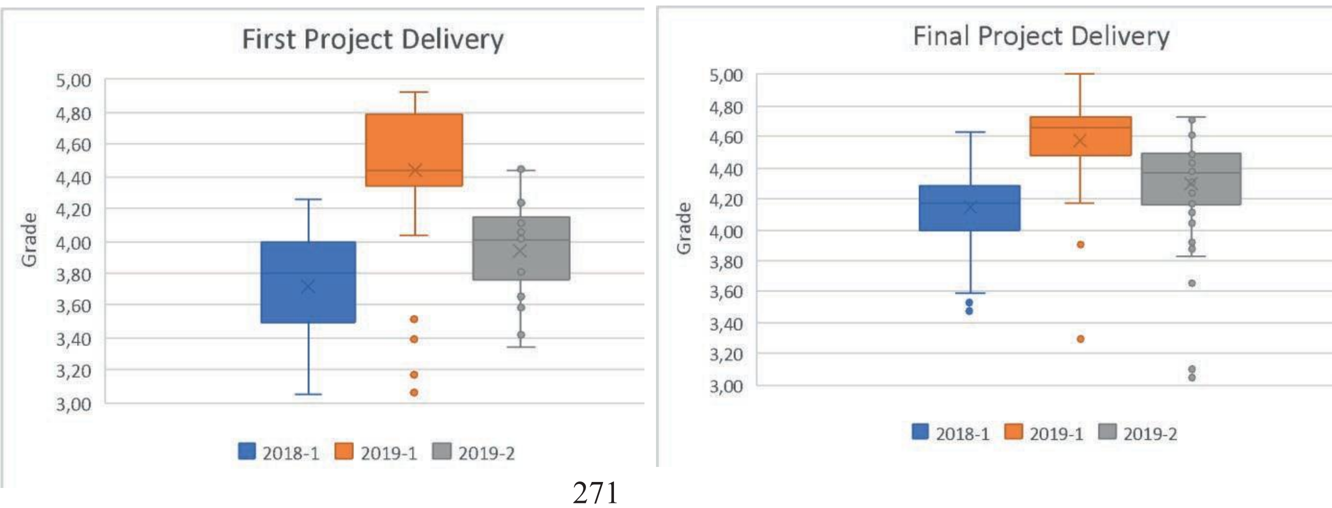


Figure 2. Statistical comparison of performance in project reports.

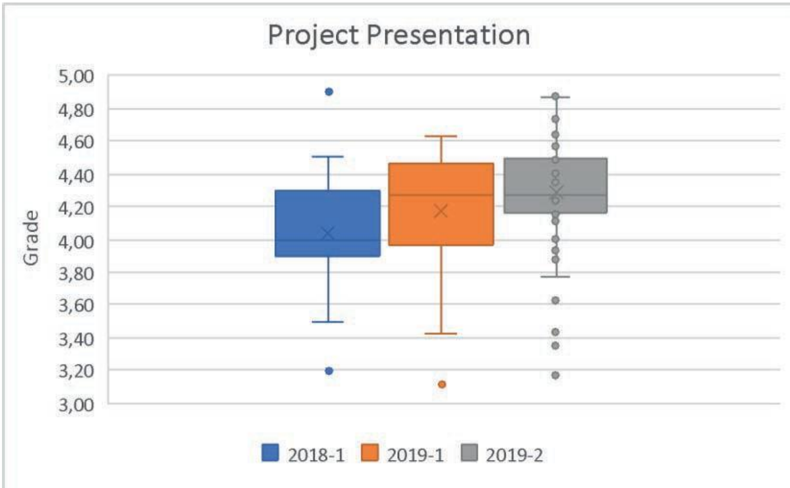


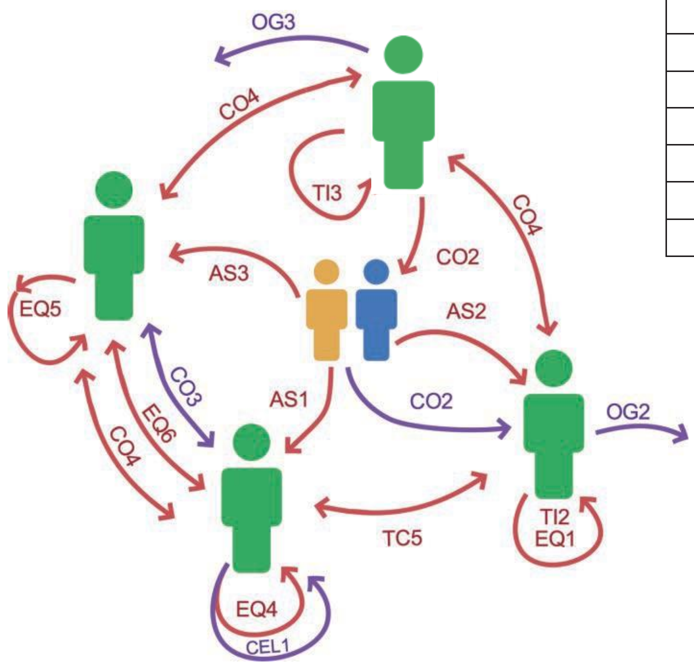
Figure 3. Statistical comparison of performance in the final project presentation.

Early analysis of qualitative data showed remarkable results regarding all the aspects of the pedagogical innovation. In this regard, data from surveys indicated that students found the PBL strategy interesting as they consider the project as an opportunity to address a real challenge, which ultimately might be useful to foster the development of analytical thinking and interdisciplinary skills. Such a finding can be explained by a well-developed complex problem situation that integrated several of the core subjects previously taken by the students, including programming, chemistry, math, and human physiology. This complexity has been considered as one of the most critical steps for the successful implementation of PO-PBL strategies (Uziak, 2016). As students travelled the intricate path for solution's development, they gradually incremented their levels of participation and reification by actively interacting with their peers and consolidating tangible products in the laboratory, respectively. As a result, students were able to build significant meaning as a direct consequence of the participation and reification processes encountered throughout the development of the project (Wenger, 1998). For example, in surveys two studentsrecalled:

"I think the most valuable thing of this proposal, is to integrate several things we have learned before in several subjects in order to create a solution for a biomedical problem. One not only learns what is taught in lectures, but interactions in the development of the project allowed us to learn more and relate it with concepts."

"I felt that I could apply all the things I've been taught, as well as I could develop the necessary skills to carry out a more rigorous research process in my career."

Further insight into the teamwork was gained with the aid of interaction maps. Such an approach allowed us to understand student-student, student-lab equipment, and student-graduate teaching assistant interactions. A representative example of a map is shown in Figure 4 shows a representative example of a map, where positive interactions such as conversations and one-on-one advice from graduate students clearly predominate. This not only provides additional evidence for the notion that the increased performance was a direct consequence of facilitated teamwork but confirmed that ideation and prototyping was conducted under a participative environment. Moreover, the development of such a rich environment can be correlated with superior technical skills and also with the possibility to exercise people-related skills. Finally, the maps also provided a tool to identify a few negative interactions that could be potentially detrimental to the development and final closure of the project as depicted in Figure4.



Code	Description
TI	Individual Work
TC	Teamwork
CO	Conversation
EQ	Use of equipment
AS	Advise from Graduate Student
CEL	Cellphone usage
OG	Interactions with other teams

Figure 4. Team interaction map. Big and small person figures represent students and graduate teaching assistants, respectively. Red arrows represent project-related interaction (positive) and purple arrows represent the non-related ones (detrimental). The inset contains a two-letter codification that specifies the type of interaction mapped, which is spelled out in the column next to it. Numbers represent the times that interactions were recorded in 5 sessions (out of 16) arbitrarily chosen.

In terms of the technological support tools deployed to help students planning their projects (Planner®) and team management (Tandem), we obtained different perceptions. Most of the students considered Planner® not very useful as they claim to have other ways to organize their project duties (e.g., WhatsApp, Messenger, Blackboard). We believe that this could be the result of insufficient time to plan the activities within the allocated time for the weekly team meeting. In contrast, a vast majority of students considered Tandem a very useful tool for co-evaluation purposes and to keep track of possible team health issues and to find proper routes to overcome them. As recounted by two students:

“After the first co-evaluation in Tandem, some of the members of the team from which the platform reported low performance started to work better in the upcoming duties.”

“The platform (Tandem) helps to learn to work more effectively as teams, as well as to assign roles to complete specific tasks. Initially, we had issues regarding workload that were solved via co-evaluation and dialogue.”

These findings strongly point out to the idea that participation and reification processes were at the core of the project interactions to favor interdependence and individual responsibility as crucial elements of teamwork. Such interactions framed by reflection and dialogue, which were facilitated by professors, are critical to promote the development of socio-cultural “soft” attributes from which students might benefit to progressively become more qualified engineers (Passow & Passow, 2017).

5 Conclusions

Learning must not be considered as an isolated or individual process in which students might be passive receptors of knowledge. On the contrary, as widely described by Wenger (1998), the process of building knowledge heavily relies on active interactions framed by the continuous progression of participation and reification. Engineering education might therefore embrace the challenge of turning from the traditional passive teacher-centered approach to an active student-centered one that is focused on the process for the development of skills and competences. Such a process has been described as critical for 21st century engineering professionals. Here, we introduced a promising PO-PBL curricular model for the integration and reasonable apprehension of the concepts of two core courses of the Biomedical Engineering undergraduate program at our institution. This holistic approach has been reported to facilitate processes where not only technical skill, but people-related skills can be successfully developed. Our intervention led to superior performance in both written reports and presentations, which was attributed to an enhanced environment for positive interactions and the continuous feedback from the teaching team. Such results are supported, as qualitative data showed that students were able to identify integration of the courses, application of concepts in more realistic scenarios through the development of projects and teamwork support, as the main drivers for learning. Consequently, we believe that this education framework can be extended to other core courses in the Biomedical Engineering curriculum, as it demonstrated a versatile route to develop essential skills in key engineering competences such as critical thinking, communication, andcollaboration.

Behind the success of our innovative proposal, there is a conscious and rigorous analysis of how the actions deployed are encompassed with the socio-cultural-concepts of participation and reification. Such analysis allowed us to specifically track down the scope and limitations of the proposal and ultimately enabled us to determine and elucidate the learning progress of the involved students. Furthermore, our mixed-method research design provided enough quantitative and qualitative data to comprehend the causality around the change in performance observed, thereby supporting the establishment of valid conclusions. Overall, we are fully aware that further analyses must be carried out to provide much more powerful insights into the correlation of positive team interactions and performance. There are some issues regarding the scope and limitations of this approach, as we are not systematically evaluating the development of competences or including active data from professors. Accordingly, for an upcoming publication we are expanding our data and including a detailed review of ABET competences as well as more robust analyses of the interaction maps and professor’s data. Moreover, multiple challenges were faced through the development of this innovative process, such as administrative inconveniences for course integration, student resistance to projects and active teamwork, changes of mentality from teacher-centered to student-centered learning, and the logistics to assure access to physical space for teamwork. Nonetheless, we would like to encourage professors and staff of the School of Engineering to actively use our approach as an initial and crucial step to prepare more flexible, comprehensive and competency-oriented curricula for the engineers in charge of tackling the upcoming societal challenges.

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Implementation of ABC Learning Design for curriculum development in an African context

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Abstract

This paper reflects an interest and effort in reforming higher education (HE) study programmes through ensuring curricula that are highly relevant to Africa's modern economic and social needs, thus equipping graduates with skills and competences for employability and self-employment.

The context of the paper is the EU funded Erasmus+ Capacity Building Project EEIS-HEA, which has the overall aims of firstly, developing study programmes which are aligned with local, national and regional needs and secondly, integrating entrepreneurship, innovation and sustainability into curricula that are delivered with the use of e-learning through student-centred learning approaches, such as, problem based learning. The project is based on cooperation between HE Institutions in East and West Africa and in the EU.

The ABC Learning Design (ABC LD) is a toolkit developed for curriculum revision at course level, but in this case, it was modified to a study-programme level. ABC LD enables a high level of engagement, creative informed dialogue and group reflection on curriculum design among time- prioritising academics. Empirically, this study is based on observations, reflection journals, surveys and focus-group interviews with participants from different ABC LD workshops conducted in five East and West African universities.

The aim of this paper is to investigate to what degree the ABC LD is applicable in an African context as a tool for instigating a problem-based learning (PBL) approach within subjects such as Entrepreneurship and Innovation, and Sustainability. The end goal will be new practical knowledge on the applicability of the ABC LD toolkit and recommendations for further development to fit a PBL approach in an African context.

Keywords: Higher Education in Africa, Curricula Development, Student-centred Learning, ABC Learning Design

Type of contribution: Best Practice Paper

1 Introduction

The EU funded Erasmus+ Capacity Building project 'Enhancing Entrepreneurship, Innovation, and Sustainability in Higher Education in Africa' (EEIS-HEA) is the context for this study. The overall objective of the EEIS-HEA is to improve higher education (HE) study programmes through ensuring curricula that are critically relevant to Africa's modern economic and social needs, thus equipping graduates with skills and competences for employability and self-employment.

The EEIS-HEA has addressed some of the challenges experienced by African universities, such as, textbook- based curricula not relevant to and not tackling local socio-economic needs, and outdated pedagogical methods of delivery of teaching that does not lead to expected learning outcomes in terms of relevant graduate competences. The problem seems to emanate from the lower levels of education. For instance, studies have shown that there are considerable gaps between the implemented and the intended curriculum in Tanzanian secondary schools; in other studies, a misalignment between the two has been considered (Kimaryo, 2011; Kira and Kafanabo, 2016). Given that the misalignment seems to emanate from the lower levels of education, lack of an appropriate curriculum that is clearly aligned with pedagogical approaches will hamper the fostering of innovation and entrepreneurial competences in higher learning institutions. Implementation of problem-based learning (PBL) in HE will, among other effects, foster competences in problem-solving, collaboration, critical thinking, creativity and communication among candidates - skills and competences that are indispensable in relation to innovation and entrepreneurship (Dahms et al. 2008). The use of e-resources in curriculum design and teaching has a role to play in developing these skills as it has been observed that the use of IT in teaching, learning and research activities in universities enables students to perform their work more easily; many students understand computer application as a method of teaching and learning that helps them long-term and improves their examination performance (Adeogum, 2003; Kira, 2016). Further, PBL will provide the opportunity to address real (authentic) local problems as means of learning and thereby equip graduates with skills and competences to promote sustainable economic growth and employment through the creation of new businesses and jobs.

To enable this transformation, EEIS-HEA will support the design or redesign of five study programmes in a collaboration between external stakeholders and five East and West African universities; Kilimanjaro Christian Medical University College (KCMUCo), State University of Zanzibar (SUZA), and Sokoine University of Agriculture (SUA) in Tanzania, and Kwame Nkrumah University of Science and Technology (KNUST) and University of Energy & Natural Resources (UENR) in Ghana. The programmes will address local socio- economic needs and apply student- centred learning approaches, and will be delivered using current and appropriate e-learning practices.

To structure the curriculum development process the constructive alignment model (Cowan et al. 2011, Biggs 2003) was applied as a model for curriculum design. Workshops were conducted with a starting point in predefined intended learning outcomes (ILOs) and assessment was considered in relation to teaching and learning activities.

The Cowan curriculum development model was applied using the following six-step model:

- Formulate outcomes of teaching in the form of intended learning outcomes for the module,
- Design assessment procedures,
- Design learning activities,
- Design teaching activities,
- Evaluate teaching via formative evaluation and summative evaluation,
- Decide on required changes of any element of teaching based on the evaluation results.

The advantage of using this model for curriculum development is that constructive alignment, a fundamental principle for quality teaching and learning in HE, is automatically assured (Fig. 1).

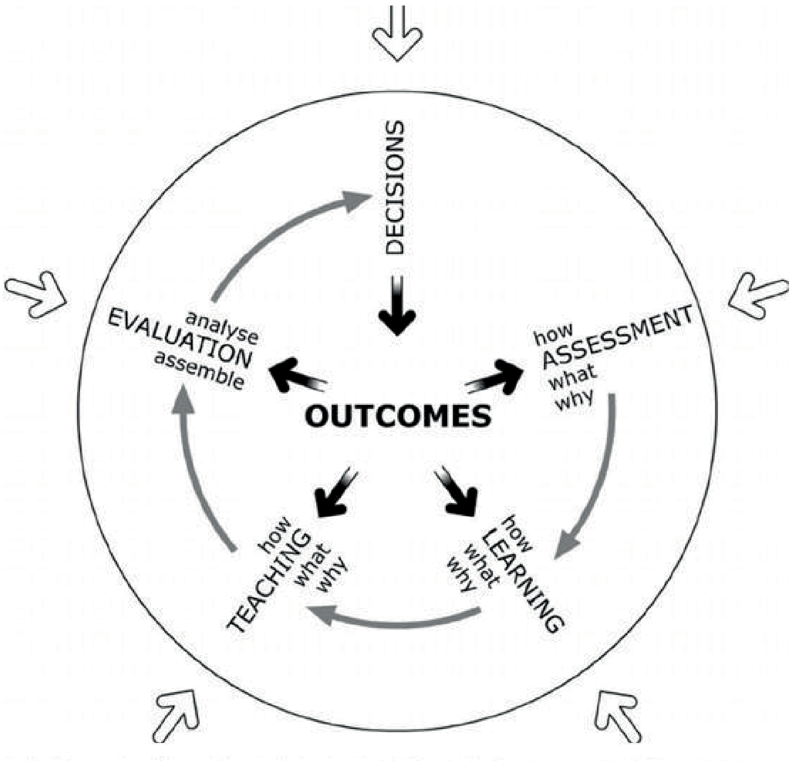

Figure 1: The Cowan Curriculum Development Model (Cowan et al. 1986)

The Arena, Blended, Connected Learning Design (ABC LD) (Perovic and Young, 2015) was introduced to the EEIS-HEA project as a tool for curriculum revision at a programme level. The ABC LD is an effective and engaging hands-on workshop which aligns well with the Cowan curriculum development model. ABC LD helps structure the development process as it provides a prepared toolkit which is easily adapted to the course or programme meant for revision, taking its offset in its ILOs.

2 What is the ABC LD toolkit and how was it applied in the curriculum development?

ABC LD (Perović and Young, 2015) is a toolkit developed by University College London (UCL Digital Education) for curriculum revision at a course level. In this study the toolkit was modified to meet the requirements of curricula at a programme level by redesigning the storyboard to contain one full 2-4 years curriculum instead of only a course (Fig. 2). Four cross-cutting subjects (entrepreneurship and innovation, sustainability, problem- based learning, and e-learning) were also added to the toolkit in order to meet the development perspective for the EEIS-HEA project (see below in Fig.5).

ABC LD is an engaging hands-on workshop where academic teams work together to create a visual storyboard outlining the type and sequence of learning activities required to meet the ILOs.
ABC LD creates a high level of engagement, creative informed dialogue and group reflection on curriculum design among even time-poor academic staff (Young, 2016). The ABC LD workshop was developed specifically for teachers in universities and has already been used successfully in UCL. The UCL team found the method to be highly transferable beyond universities and other universities and colleges in Europe as well as North and South America have also started to use the method. The key to the ABC LD methodology is pace, engagement and collaboration. In just 90 minutes using a prototyping workshop, teams co-create an outlining visual storyboard. (Fig. 2).

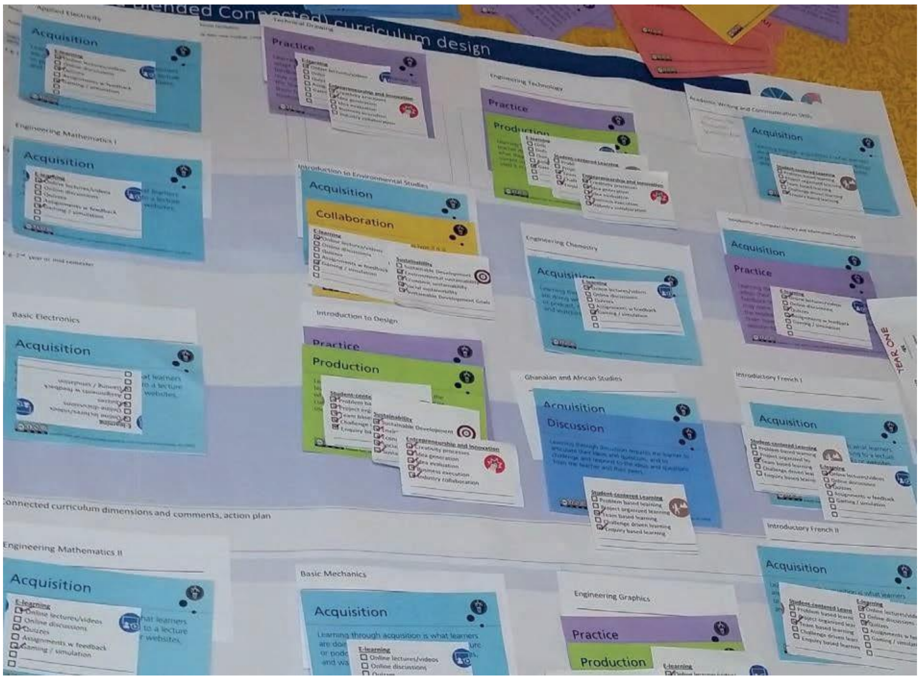

Figure 2: Storyboard from UENR ABC LD Workshop, 3 May 2019

Assessment methods are included and cross-programme themes and institutional policies may also be integrated into the process. ABC LD has been found to be particularly useful for new programmes or those changing to a wholly online or more blended format (Milani et.al. 2017).

The main part of the tool is a card-set with the six learning types (Fig. 3): Acquisition, Inquiry, Practice, Production, Discussion and Collaboration, based on the Conversational Framework of Laurillard (2012; Perović and Young, 2015).

Figure 3: The six cards used in ABC LD, slightly adapted (e.g. Inquiry -> Investigation)

Five study programmes were selected for development, one in each African university. The programmes were described by an overall purpose and ILOs were clarified for each programme and course. The settings for the workshop were seminar rooms with the possibility of arranging tables and chairs into three to seven individual group arrangements. Our version of the ABC LD workshop was organised in the following manner:

- Before the actual workshop, the participants worked with the curriculum ILOs for several hours in order to share a common agreement and understanding of them.
- After a brief presentation introducing the ABC LD toolkit elements and their pedagogical background, the participants were placed in teams of six to eight teachers and recent students.
- The storyboard, large A1 sized paper (See Fig. 2), was filled with time organised course cards (one for each course) for the whole curriculum. In some cases, each team focused on only one year of the programme. The groups reviewed the match between ILOs and the present programme and suggested modifications.
- The teams formulated a tweet size description (unique selling points) of the programme and characterised the blend of learning types (Fig. 4).

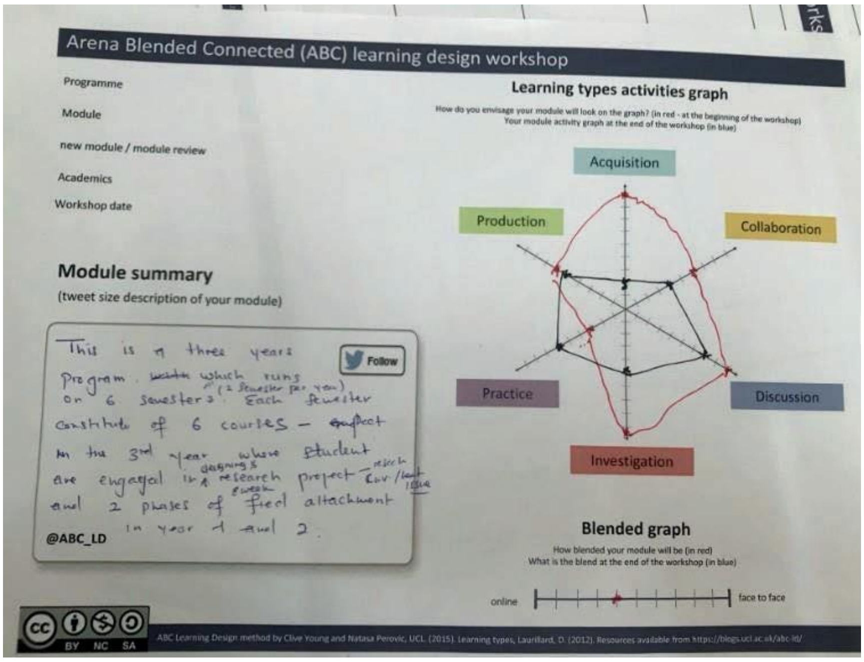

Figure 4: Tweet from SUZA ABC LD Workshop, 2nd May 2019

- In the next round the teams added one or two best characterising learning type cards to each course card, and discussed the picture it created of the blend of learning in each semester.
- Since the aims and objectives of the EEIS-HEA project are to improve the curriculum regarding the cross-cutting subjects entrepreneurship and innovation, sustainability, problem based learning, and e- learning (Fig. 5), the teams placed cards with these headings on the courses where it was particularly relevant to incorporate a cross-cutting subject. They could write quick notes on the cards, so each course could be tagged with useful input to further development. This exercise aimed to give an insight into how well each cross-cutting subject was distributed in the curriculum.

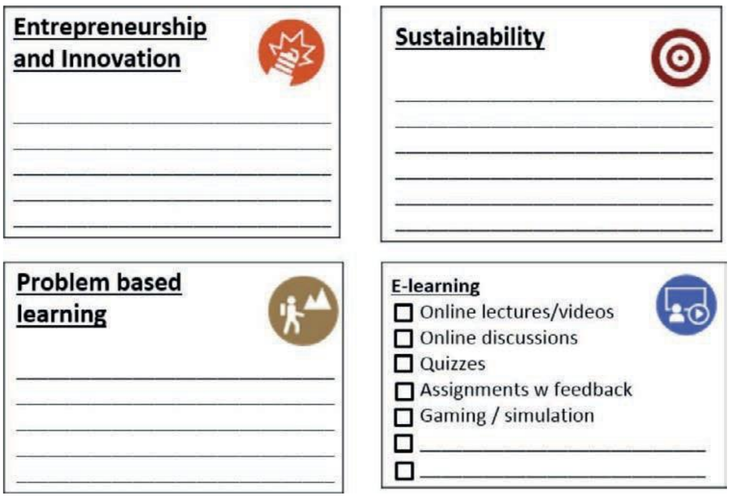

Figure 5: EEIS-HEA cross-cutting subject cards

- At the end the teams once again reviewed the ILOs against the (possibly revised) course plan, and filled in a who-does-what table on how to move on in practice.

The workshop typically took 3-4 hours, significantly more than the 1½ hours stated in the original version of the ABC LD (Perović and Young, 2015). After the workshop the resulting storyboards were packed and photographed to be used in further curriculum development.

3 Research Approach

Empirically, this study is based on observations, reflection journals, surveys and focus-group interviews with participants from the five different ABC LD workshops conducted in three East and two West African universities.

The observations were conducted both by researchers from EU universities, who organised and facilitated the ABC LD and by workshop participants. Each participating university was also asked to prepare a reflective learning journal, including evaluation and reflection on the ABC LD process and outcomes. Also, follow up focus-group interviews were conducted with groups from seven to twelve participants. In addition, a survey was sent to all workshop participants in the five African universities. In total 37 participants responded.

The workshops were organised as described above and conducted in five African universities:

- Kilimanjaro Christian Medical University College (KCMUCo), Moshi, Tanzania
- Sokoine University of Agriculture (SUA), Morogoro, Tanzania
- State University of Zanzibar (SUZA), Zanzibar, Tanzania
- Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana
- University of Energy & Natural Resources (UENR), Sunyani, Ghana

The ABC LD workshops were conducted in spring 2019 in connection with local teacher training activities as part of the EEIS-HEA project activities. The number of participants varied from 20 to 40 and was composed of academic teaching staff, programme coordinators and students.

Figure 6: Photo from the ABC LD workshop at KCMUCo, May 2019

At the workshops, participants discussed courses and project modules in relation to the redesign of their Programs, as photo (Fig. 6) shows.
Workshop facilitators were from the University of Copenhagen, Denmark; Aalborg University, Denmark; the Royal Institute of Technology, Sweden; and the Polytechnical University Barcelona.

4 Experience of Running and Participating in the ABC LD Workshops in the Five African Universities

Observations by facilitators indicate that the format of the ABC LD workshop and presence of colleagues and students clearly stimulated wide-ranging dialogue on the purpose of the programme, teaching and assessment methods, and also the student experience. Because we were looking at a whole study programme/education curriculum, the topic was broader and the participants were much more diverse than if we had been redesigning a single course. A lot of time was needed for all to comprehend the complexity of the ILOs and the programme layout and, therefore, much more time was needed than the stipulated 90 minutes for a usual ABC LD exercise. However, it was also a great strength of the workshops that the teams could discuss and share their approaches across the whole programme using the same language and illustrations, aiming for a more cohesive student-centred approach across the courses and modules of the study programme. Another observation was that the participants had some difficulties in applying PBL- project units into the curriculum – the storyboard was entirely filled with modules and courses (and no projects) because that was the layout of education at the five universities. Some workshop teams, however, added capstone project units to the study programme.

The participants in the focus-group interviews were asked the following three questions: Q1) In which ways was the ABC LD workshop useful? Q2) Which components were addressed in a useful way? And Q3) how would you like (if you do) to follow up on the ABC LD workshop? These are some of the answers:

Q1) In which ways was the ABC LD workshop useful?

It [ABC LD] gave an opportunity to map the curriculum and then determine which courses should be deleted, retained and/or moved. The number of courses has always been a problem. We did 'cut down' by merging some courses but without reducing credit hours.

The ABC LD gave overview and input on how to do the mapping – but not enough time.

We modified the curriculum by merging and deleting according to whether courses were relevant or irrelevant. This process was initiated by the ABC LD workshop.

Having students looking at the curriculum was a very good thing – students who had gone through the courses. Discussions were factual, not accusing, and took place in an open, honest and polite way. Some of the students were student assistants who had already graduated, so they had nothing to lose. The workshop made us talk among ourselves and that gave a better position to see the overload.

It was useful because it gave us a possibility to voice some concerns that we were not bold enough to complain about in class – in the ABC LD workshop we had the chance.

Q2) Which components were addressed in a useful way?

The programme structure was the most useful component. And it helped to see how and where to embed the four cross-cutting areas into the programme structure.

The overview of the programme structure [Storyboard] – we have used that and it has been a big benefit. The visual impression of the big picture makes it easy to explain to outsiders.

The ABC LD workshop did not address the issue of student time – but it showed the problem of overload – students should have a reasonable workload. We have made room for options in the new curriculum.

The workshop helped us see links between different subjects – we realised how these courses are linked. We could identify overlapping course elements.

Q3) How would you like (if you do) to follow up on the ABC LD workshop?

> *The first time we did not have enough time, there is a need to do another ABC LD workshop at programme level. There is also a need to do the ABC LD workshop at course level.*
>
> *ABC LD materials would be good, then we could do the workshop ourselves.*

A survey was conducted as an evaluation of training on the cross-cutting subjects and the ABC LD workshop. The three questions below were also asked as a part of the survey.

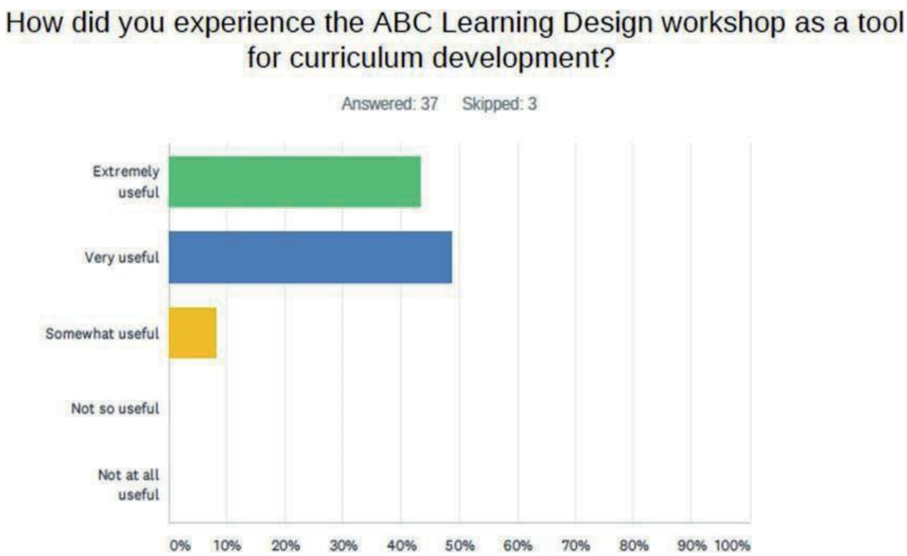

Figure 7: Experience the ABC Learning Design Workshop as a tool for curriculum development?

The response to the utility of the ABC LD process was particularly positive, 91% answered that it was 'Very useful' or 'Extremely useful', only 8% thought it was 'Somewhat useful'.

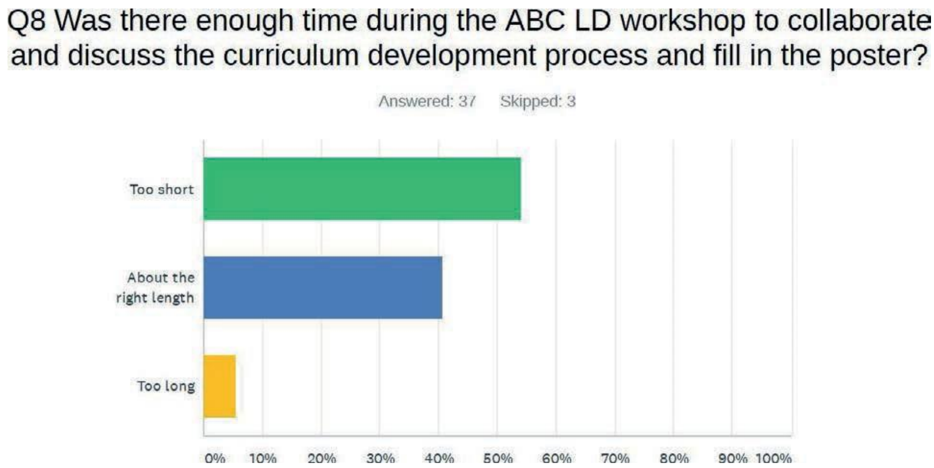

Figure 8: Allocated time for the ABC Learning Design Workshop?

As the pace of the ABC LD process seemed to be a problem the survey contained a question regarding time. The answer was clear, 54% of the respondents still suggested that they had too little time to go through the ABC LD process (even though they had 3-4 hours), but 40% thought that it was about right length of time.

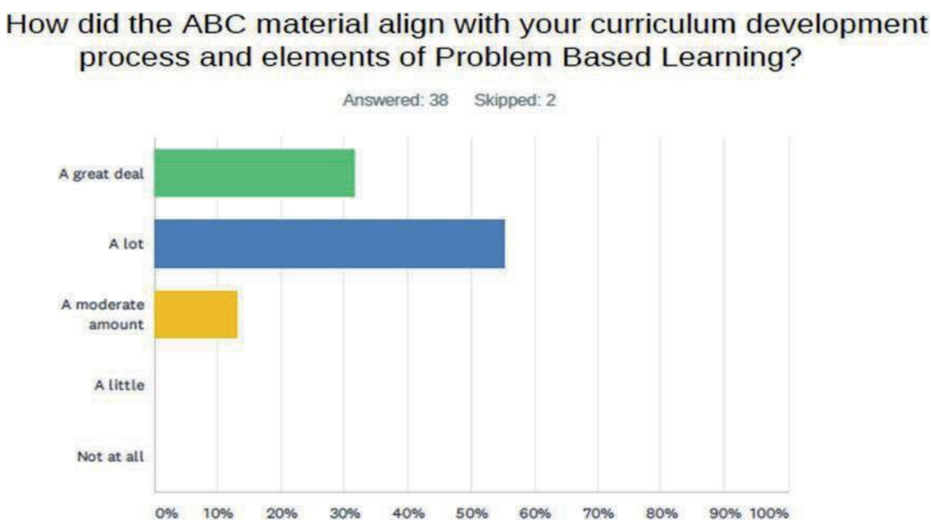

Figure 9: ABC material align with curriculum development process?

The respondents also indicated an alignment between their curriculum development process and PBL, 32% answered that there was a great deal of alignment, whereas 55% stated a lot.

In general, the survey showed great satisfaction with the ABC LD workshops, which was also the observation noted by the facilitators organising the process. Great engagement and collaboration between the participants was observed.

5 Conclusions and Recommendations

The aim of this article was to investigate to which degree the ABC LD is applicable in an African context as a tool for instigating a PBL approach, e-learning, entrepreneurship and innovation, and sustainability. The experiences and outcomes of applying ABC LD in the EEIS-HEA curriculum development project were rewarding. We created new knowledge on the applicability of the ABC LD toolkit and recommendations for developments to fit a PBL approach.

The basis of the ABC LD methodology is pace, engagement and collaboration. Regarding pace, both the focus group interview and the survey indicated that workshop participants experienced a lack of time when completing the ABC LD process and filling in the storyboard, even though it was extended compared to the original layout for courses. A main reason is that the task is different with a full curriculum review and possibly larger. It may also be due to poorly elaborated ILOs for the study programme and the huge number of courses each programme contained. Covering extensive content is possible because teaching in most of the African Universities at the undergraduate level is teacher-centred (Govender, 2019), where content coverage is more important than thinking about developing students' investigative skills. Also, teacher- centred methods, for instance lecturing in the context of Africa, makes little use of e-learning facilities beyond projection of lecture notes in front of the class. This means that partly, instructors were also consuming time in the ABC LD workshop thinking about the ways in which e-resources can be effectively utilised in student-centred perspectives.

From the focus-group interview, *´the number of courses has always been a problem'* (12-16 courses per year in all universities), presumably refers to both student work overload, which became obvious in some programmes, and also the feeling that it is difficult to do large enough projects when many courses cut the learning into pieces. Participants noted the value of the programme structure; *'The [ABC LD] programme structure was the most useful component. And it helped to see how and where to embed the four cross- cutting areas into the programme structure'*. In general, the structured process and also the visualisation was noted by the participants as making *'… it easy to explain to outsiders'*. In the best cases, each course gained valuable notes from the process which those responsible for the course may work with. The process also '*gave us the possibility to voice some concerns',* but the general impression was that *'discussions were factual, not accusing, and took place in an open, honest and polite way'.* It shows again that the main benefit of ABC LD is that it provides a good opportunity for discussion between different stakeholders, based on a shared clear overview, that would otherwise not occur. In general, the implementation of ABC LD for curriculum development in an African context was beneficial to the process and very well received by the participants; '*The ABC LD materials would be good, then we could do the workshop ourselves'.*

To structure the curriculum development process the EEIS-HEA project applies the constructive alignment model (Cowan and Harding, 1986; Biggs 2003); this six step-model has a starting point of ILOs and then moves on to consider the assessment methods applied before deciding on the learning and teaching activities. The ABC LD structure also has a starring point in ILOs, but in our version with the study programme, it moves straight to deciding on the learning and teaching content and activities and does not take into consideration the assessment methods - unlike the ABC LD version for course level. This, according to Biggs (2003), is 'risky' as students obviously prepare for passing examinations e.g. multiple-choice and/or reflective assignments, which calls for different learning activities. Considering the high number of courses, assessment is better considered in the course version of ABC LD.

Also, our ABC LD was applied to a course founded curriculum; this is reflected in the toolkit where the cards refer to the language of learning models as 'courses'. When developing a curriculum for a PBL approach the language of the cards should be re-considered as the term 'courses' reflects a certain combination of learning activities in most cultures.

Therefore, in order to simplify the use of the ABC LD model in curriculum design and development in various contexts, firstly, the key issues that need to feature in the curriculum should be clearly understood by the participants; in our context these were the elements of e-learning, entrepreneurship, sustainability and student centred learning perspectives. Such an approach will reduce the number of questions about the meaning of these elements during the actual activity of designing the curriculum.

Secondly, if the curriculum design involves shifting from a teacher-centred to a student-centred model, it is likely to involve more resources at the implementation stage. Therefore, curriculum planners may need to think about the availability of such resources, including the processes involved in mobilising them for easier accessibility by students, before venturing into the curriculum design process. For instance, if a curriculum based in engineering that used to be teacher-centred in developing countries needs to be modified to become student-centred, participants need to be aware of the resources available both directly in the institution and indirectly outside the institution for field attachments. This is where it will be possible for curriculum designers to identify how and when ABCD LD aspects should be applied to achieve the stated learning outcome.

Thus, the next natural step would be to go one step deeper and do the ABC LD exercise at course level, which has also been suggested by some of the partner universities. Further study should be based on determining the extent to which curriculum designers have the knowledge, skills and motivation to apply e- learning, sustainability, entrepreneurship and student-centred learning perspectives in their everyday teaching and learning processes. This could serve as a milestone for training participants on curriculum design and development using the ABCD LD model in various programmes at different levels of education.

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Using different taxonomies to formulate learning outcomes to innovate engineering curriculum towards PBL: perspectives from engineering educators

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Abstract

Designing modern engineering curricula requires integrating the United Nations' Sustainable Development Goals (SDGs) and generic employability skills, focusing on student-centred learning, and explicitly including learning outcomes about knowledge, skills, and competences. There is the need thus for tools that help teachers and boards to address these demands and assure quality in educational processes and outcomes when revising and changing curricula. Higher education institutions have been developing different quality assurance strategies. However, from a teaching and learning practice perspective, there are concerns on whether such strategies guarantee curriculum coherence, especially in terms of ensuring progression and alignment between learning outcomes and more student-centred learning activities, such as problem-based learning (PBL).

This paper discusses the above coherence issues by addressing the following question: What are strengths and weaknesses in using taxonomies to analyse learning outcomes as mean to promote curriculum innovation and PBL implementation?

The paper takes the point of departure on formulation of learning outcomes using Bloom's revised, SOLO, and Feisel-Schmitz Technical taxonomies and in which ways they support engineering educators in re-design their courses towards PBL. More specifically, the manuscript discusses: a) the similarities and differences between different taxonomies; b) strengths and weaknesses of taxonomies to analyse learning outcomes for engineering education and PBL, taking the point of departure four engineering courses as case examples. We categorise different courses' learning outcomes using the referred taxonomies, and reflect on their suitability for categorising and formulating the learning outcomes in engineering education. The results enable discussing the suitability of the taxonomies in more generic settings, their limitations in formulating learning outcomes relevant for engineering practice, namely non-cognitive learning outcomes and transversal skills, and making recommendations towards improved curriculum alignment in engineering education for PBL.

Keywords: Learning outcomes taxonomies, engineering education, curriculum innovation, PBL

Type of contribution: conceptual paper

1 Introduction

The current societal and technological transformations induced for example by digitalisation, automation, and sustainability among others, are implicitly pushing for introducing new types of learning outcomes in classical engineering education programs. Besides a high level of technical expertise, future engineers will need more complex abilities for solving unprecedented problems while communicating and working within interdisciplinary teams. Engineers are more and more pushed towards acquiring a web of competences tying, among others, innovation, creativity, adaptability, flexibility, and dealing with a more uncertain world than before. Educational policies, institutional strategies and management boards recognise the need for active learning environments and student-centred curriculum in order to develop the aforementioned skills and competences. However, it is engineering educators and practitioners that operationalise change by, for example, revising and reformulating their courses' learning outcomes, learning activities and assessment approaches.

Problem-based, project-organised (PBL) and 'Conceive-Design-Implement-Operate' (CDIO) are examples of student-centred learning approaches that are gaining popularity in engineering education. In a PBL environment, groups of students formulate and solve real, authentic problems. PBL roots in cognitive and socio-constructivist theories, recognising students' role in constructing knowledge and predisposition towards learning as well as their experiences, prior knowledge and cognitive structures as fundamental components of how they learn (Savin-Baden and Howell, 2004; Kolmos et al, 2009). PBL is characterised as problem-based, collaborative, contextual, experiential, exemplary, participant-directed, emphasise relation theory-practice, interdisciplinary and project-organised (or case-organised). To implement PBL, institutions and teachers undertake a process of curriculum and course change, following PBL characteristics and the principles of curriculum alignment. Based on PBL curriculum examples, Kolmos et al (2009) pointed the curriculum elements and their alignment, which are (i) learning objectives and knowledge, (ii) type of problems, projects and lectures, (iii) progression, size and duration, (iv) students' learning, (v) academic staff and learning, (vi) space and organisation, (vii) assessment and evaluation. Changes in one of the curriculum aspects implies changing the others as well. From here, it is necessary to determine the different disciplinary knowledge required to solve the problem, the duration, resources needed (e.g. infrastructures and lectures), the role of teachers and students, and the assessment methods to assess the learning objective initially framed. In sum, the PBL curriculum elements are interrelated and provide a holistic representation of the curriculum. In addition, each of the elements presents a landscape of possibilities leading to a variation of PBL models designed and implemented in engineering education, at system, programme, or course levels (Barrows & Tamblyn 1980; Savin-Baden & Howell 2004; Kolmos et al. 2009).

Literature claims that PBL promotes the development of learning outcomes in all levels of taxonomies, therefore we see a need for developing practices and a taxonomy that helps the teacher to analyse the learning outcomes and from there develop more deep learning activities based on PBL. It is hard to evaluate practices without a proper framework, especially if we search for the connection between developing learning outcomes and its effect on learning activities.

Less content coverage, more time for preparation, lower evaluations, students' lack of knowledge, re-build one's identity as teacher, lack of "how-to-do" knowledge, difficulty to predict learning outcomes and ensure "quality control" are some of the barriers teachers face when changing their courses towards active, student-centred learning such as PBL (Michael, 2006). In our specific case as engineer educators, we frequently experience the reformulation of learning outcomes as a point of departure to innovate our courses and engineering programmes as one of the most challenging tasks. For example:

- how to use appropriate formats, terms, and standards, in order to avoid descriptions and formulations that may be interpreted in different ways by different stakeholders, including students and employers;
- how to make explicit and time-related inter-relations of the curriculum's different courses and modules, in order to avoid structural progression issues, such as content overlapping, misalignments and curriculum overloading,
- how to highlight "learning-ladders" (i.e. learning progression) by making expectations, roles and responsibilities explicit and clear to students (e.g. what they need to know and why, for different contexts and challenges, professionally and socially), and in order to motivate students to develop deep learning (i.e. create intention to understand, vigorous interaction with content, relate concepts with everyday experience, relate ideas with previous knowledge, relate evidence to conclusions, examine logic of the argumentation (Savin-Baden and Howell, 2004).

In the ideal situation an engineering programme is created from a future role of a competence needed or assumed. From the expected final competences learning goals and courses are created and designed to achieve these goals for the graduated engineer. Therefore, the programme design shall origin from a top-down perspective and not bottom-up, i.e. (existing) courses are put together to form the program.

There are a few conceptual pedagogical frameworks capable of supporting engineering educators in reformulating their courses' learning outcomes, developing aligned learning activities and assessment methods in order to change their courses coherently and systematically towards PBL. For example, the constructive curriculum alignment (see for example Tyler, 1949; Biggs, 2003; Cowan et al, 2004) and taxonomies to formulate learning outcomes (see for example Bloom's revised, SOLO, and Feisel-Schmitz's Technical taxonomies). In this paper, we focus on the point in the formulation of learning outcomes and their implications for active learning and PBL at course level.

According to Biggs (2003), each course builds on previous knowledge, either prerequisites from earlier courses or from learning outcomes within the course. Therefore, each course has its own hierarchy of learning outcomes .Taxonomies for formulation and analysis of learning outcomes include different types of knowledge and verbs that describe a performance of the level and type of knowledge learned. The taxonomies provide support and guidance to engineers educators to re-formulate the learning outcomes of their courses, and programmes. However, they are not clear on how to formulate learning outcomes relevant for engineering education and practice, show explicit hierarchical progression and development within engineering concepts, formulation of transversal skills and non-cognitive learning outcomes. Furthermore, it is also needed to integrate the taxonomies frameworks as part; for example, IT tools to enable educators to continuously align their courses' learning outcomes, with PBL approach and with societal and professional trends. In this paper we focus on learning outcomes taxonomies and how they can better serve engineering educators to re-formulate learning outcomes at course level. We start by describing three different learning outcomes taxonomies, namely Bloom's (revised) taxonomy, SOLO taxonomy and Feisel-Schmitz Technical taxonomies, see Section II. The taxonomies are then used as a framework to analyse the learning outcomes of four existing courses in different engineering programmes at two different universities in Norway and Sweden. The analysis is presented and discussed in Section III. We finish the paper with a conclusion section, where we reflect on the limitations of the taxonomies used and their implications to implement student-centred methodologies such as PBL.

2 Taxonomies for describing learning outcomes

In this section, we revise three types of taxonomies commonly used to describe learning outcomes and respective knowledge levels. These revisions are, obviously, rather concise and containing information pertinent only for the purposes of the discussions raised in this paper. To know more, we suggest the readers to consult the literature we refer to.

2.1 The Bloom's revised taxonomy (Krathwohl et al. 2002)

This taxonomy models learning as the intersection of a *Cognitive Process Dimension* (CPD) and a *Knowledge Dimension* (KD). Each dimension is then represented as a series of hierarchical steps, each step capturing a different level of complexity. The CPD can be described as a series of levels that go from *Concrete Knowledge* to *Abstract Knowledge* by the means of so-called *Objects* (usually a noun). For example, knowledge may be listed as *Factual*, *Conceptual*, *Procedural, Metacognitive*, and so on. Instead, the KD can be described from lower order thinking skills to higher order thinking skills using so-called *Actions* (usually a verb). Examples are *Remember*, *Understand*, *Apply*, *Analyze*, *Evaluate* and *Create* (Andersen & Krathwohl (2001 p. 46)). Importantly, the steps in the CPD include both procedural and conceptual knowledge; and since procedural knowledge may not be more abstract than conceptual knowledge in all steps, the steps in the CPD are not entirely hierarchical. The same non-hierarchical nature can be argued also for the KD, since similar reasonings apply to this dimension.

2.2 The SOLO taxonomy (Biggs & Tang 2011 p. 86ff)

The Structure of the Observed Learning Outcome (SOLO) taxonomy attempts to model whether learners capture relationships and connections or not among different learning outcomes. The resulting classification is thus in terms of complexity of the puzzle that learners construct in their mind: this hierarchy is modelled through five taxonomic levels (i.e., *Prestructural*, *Unistructural*, *Multistructural*, *Relational*, and *Extended abstract*) and a list of verbs associated to each level. More precisely,

- *Prestructural* indicates a generally insufficient knowledge about a specific learning objective,
- *Unistructural* indicates the situation where the learner has captured some few salient aspects of the learning objective, i.e. define, identify, draw, label, match or follow a simple procedure.
- *Multistructural* indicates a situation where the learner captured several aspects of the objective, but is still not able to relate them, i.e describe, list, outline, complete, combine, calculate.
- *Relational* indicates the capability of capturing the relations mentioned above, i.e. sequence, classify, compare and contrast, explain (cause and effect), analyse, apply etc.
- *Extended abstract* indicates the capability of generalizing the relations above to yet untaught learning objectives, i.e. generalise, predict, evaluate, reflect, hypothesis, theorise, create, prove etc.

The first three levels relate to a "quantitative" phase of knowledge, while the latter two to a "qualitative" one that promotes deep learning.

2.3 The Feisel-Schmitz Technical taxonomy (Feisel 1986)

This taxonomy divides all learning in technical subjects into four performance objectives. There is also a fifth, Judge, but the inventors considered it "beyond the scope of most technical education programs", and is therefore not normally taught in traditional University programs. However, the ability to solve complex problems is one of the most important competencies engineers graduates should have in order to operate in a globalised and volatile profession. This requires the ability to judge as Feisel states.

- *(ability to) Define*, i.e., learning the terminology of a discipline and be able to communicate it efficiently with others who are similarly prepared,
- *(ability to) Compute*, i.e., perform required formal computations using specified formulas or procedures,
- *(ability to) Explain,* i.e., understand the phenomenon well enough to describe it orally or mathematically at the point where creative analysis could be performed,

- *(ability to) Solve*, i.e., problem definition, analysis, synthesis, and to a considerable extent, the process of design,
- *(ability to) Judge*, i.e., to evaluate multiple solutions, select an optimum solution, evaluate supporting evidence.

Since the taxonomy is a part of a paper on creating a system for self-education, it shall be noted that the writer especially stresses learning objectives other than the explicit course goals, i.e., *orthobjectives* (objectives which bear almost no relation to the explicit goals of a course; orth=orthogonal) and *perobjectives* (a capability or attitude that is taught throughout the learning experience). A more commonly used term is transversal skills, but there are differences between them, especially for the *perobjectives*. We note that the aim of this manuscript is not to make a clear distinction or define them.

2.4 Comparing the three taxonomies to formulate learning outcomes

The three learning taxonomies have in common the following aspects:

1. They all use **active verbs** to express students' performance. The verbs do not represent knowledge per-se, but rather refer to objective and explicit behaviours that show learning is taking place. They are particularly relevant to define the activities students need to perform to learn a given content, and be assessed;
2. They all present **hierarchies and subsuming levels** of learning outcomes to capture increased complexities of different cognitive tasks. This means that the learning outcomes and respective learning activities may be organised accordingly to these developmental and progressive levels to optimize learning. It means that knowledge is not only about *know that* but also, *know how*, and *why*, in conjunction;
3. They all consider **different types of knowledge**. Namely, factual, conceptual or declarative (knowledge as content, broken into facts and principles - *know what*), procedural (derive knowledge from factual knowledge and apply to solve problems - *know how*), metacognitive (knowledge about the interplay between person, task, and strategy characteristics - *know why*) (Flavell, 1979; Crawley et al 2014; Eustace, 1999).

Importantly, the above common aspects provide some consistency among the three taxonomies. What defines each of them is thus the different use of the various verbs, the differences in the hierarchies and subsuming levels, and the different types of knowledge addressed by them.

On the other hand, the three analysed taxonomies present the following limitations:

1. **They have generic character**, i.e., they do not consider the disciplinary domain, the nature of discipline concepts and how they build on each other, with partial exceptions for the Feisel-Schmitz Technical taxonomy (Feisel 1986), suitable to formulate learning outcomes for technical fields even if not presenting an explicit hierarchical structure and types of knowledge like the other two. For example, engineering sciences require learning complex concepts that have hierarchical nature. Learning these concepts depend on a network of related concepts, or prerequisites (Eustace, 1999). Engineering curricula include many complex concepts that are both core knowledge of one course and prerequisites for others. Structuring learning in engineering programmes and courses also means organising its learning outcomes hierarchically to observe students' learning. Gagné et al (1962) revealed that learning successive "learning sets", i.e. learning outcomes, was dependent on mastering prior sets. This is particularly relevant for learning outcomes for complex concepts, and how to organise learning activities, being more centred in the teacher or being more centred in students. This is especially important for the PBL environment, where students become responsible for their own learning and construction of knowledge. There is a change of ownership, i.e. students become more active, responsible and autonomous learners, whilst the teachers are not

transmitting knowledge but rather scaffolding and facilitate students learning. Designing learning outcomes for PBL also means that it is needed to align them, their complexity and hierarchical nature, with students' and teachers' roles in the learning process.

2. **The analysed taxonomies do not consider non-cognitive learning outcomes**, such as emotional maturity, empathy, interpersonal skills and collaboration, communication, that are in demand for future engineering practice. The current trends in engineering education (e.g., industry 4.0, digitalisation, automation, and sustainability) call for a new set of skills and competences that go beyond the technical expertise. Examples of these competences are: systems thinking, complex problem solving, ethical and professional responsibility, creativity, lifelong learning, interdisciplinary collaboration, adaptability and flexibility, digital literacy, sustainable mindset (Guerra et al, 2017; Guerra and Nøgaard, 2019). It is proven that PBL promotes the development of the aforementioned skills and competences, see for example the increase of publications in engineering education research and practitioner literature, such as in the Journal of Engineering Education, European Journal of Engineering Education, International Research Symposium on PBL (IRSPBL) proceedings, and Project Approaches in Engineering Education (PAEE) conference proceedings. The three taxonomies analysed in this manuscript do not consider the non-cognitive dimensions of learning, such as emotional dimension (Illeris, 2008), therefore it is challenging to formulate non-cognitive learning outcomes, or transversal skills, under the frame of these three taxonomies.

In sum, changing engineering courses to more student-centred approaches by implementing PBL requires a reformulation of learning outcomes, organised hierarchically and designing aligned teaching and learning activities. In hybrid PBL models, where the curriculum includes lecture-based courses and PBL projects, the learning outcomes are not only structured hierarchically but also organised in more teacher-centred activities, e.g. lectures, and more student-centred activities, e.g. project work (Aalborg University, 2019). The following section discusses the use of the three taxonomies to re-formulate learning outcomes in four engineering courses.

3 Strengths and weaknesses of learning outcomes taxonomies for engineering education: four case examples

In the following we discuss the use of the taxonomies to complement the existing descriptions of intended learning outcomes of four engineering courses from two nordic universities. The aim is to use the taxonomies, and discuss their application in: (i) formulating the course goals and expected learning outcomes, (ii) describing at what level each outcome should be mastered to reach a deeper understanding, (iii) using the taxonomies for constructive alignment purposes (i.e., planning and designing exams and lessons in connection with the courses' goals), and (iv) improving the learning activities towards PBL.

3.1 Description of the courses used as case examples

The engineering courses for which we tested using the taxonomies defined above are:

C1) 1TE661, Signals & Systems at Uppsala University, 5 ECTS credits

C2) 1TE717, Digital technology and electronics at Uppsala University, 10 ECTS credits

C3) 1TE770, Analogue electronics at Uppsala University, 10 ECTS credits

C4) TTK4260, Multivariate Data Analysis at NTNU in Trondheim, 7.5 ECTS credits

These courses employ different active, student-centered learning approaches and strategies. The course 1TE661 (case C1) is usually taught within a 6 to 8 weeks teaching period in two different settings: 1) a fairly classic, traditional setup with 13 lectures and 7 tutorials, where active participation is encouraged by using clickers and small group discussions interrupting the lectures, and 2) in a setup where students are given all course material (including course script, exercises with solutions, lecture videos) and additional material such as a list of course goals specifying the requirements to pass the course, how they connect to the course material, and a week-plan suggesting what students should focus on in each course week. Then, students are divided into groups of up to eight students (by their choice) and each group is given a group tutorial of one hour each week. For details, please see Staffas and Knorn (2019). Note that, the course material and requirements as well as the course goals remains the same in both setups.

In the second course, 1TE717 (case C2), the students begin with 5 weeks of interactive lectures, exercises sessions and labs. This first part introduces the core facts and procedures related to electronics. The second part of the course consists of 4 weeks of group project work. Each group freely selects a “product” that must be developed, and a “client/consultant” (teaching assistant) is assigned to each group. The students have to systematically conceptualise, design, and implement a working prototype fulfilling the “product’s” specifications and requirements. The teaching assistant has a dual role of stating the product’s requirements and inquiring about the status of the product (client), as well as providing high-level assistance at the conceptualisation and design stages (consultant).

The third course, 1TE770 (case C3), uses a working model where most of the lectures are micro lecturing online and learning with the teacher is mainly through group work with simulations based on the course goals. In the lecture hall, focus is on what the connection is between this week’s learning goals and the real world.

Last but not least, the course TTK4260 (case C4) is a 13-weeks long course on data analysis that includes flipped classes, peer instructions, and home assignments that partially conform with the PBL approach (in the sense of pushing students to learn about a specific part of the course through solving a specific problem described during the frontal lessons by the instructors). The original intended learning outcomes for this course were written in a way that emphasized non-cognitive knowledge (especially creativity, critical thinking, and ability to work in teams), even if this was seen as a naive strategy by the instructors.

3.2 Description of the evaluation form

The three taxonomies above were used to analyse the course goals of the courses in 3.1. To better describe the methodology used to perform this analysis, the following box exemplifies the operations performed for course 1TE770 (case 3).

Box 1. Example of the form used to revise the course goals using the three taxonomies investigated in this manuscript.

Pre-existing course goal: ‘calculate the gain for a resistive OP circuit with negative feedback’

Reformulation according to Bloom’s Revised Taxonomy (BRT):

- analysis of the prerequisites: **Apply** Ohm’s law; **Apply** Kirchoffs laws; **Apply** Equation system
- rephrasing of the intended learning outcome:
  - **Understand** the consequences of negative feedback for the voltage on the inputs;
  - Express $U_{UT}(U_{IN})$ where U_{IN} is the difference of the voltage inputs on + and –. This is at the **Apply** and **Analyze** level

Reformulation according to SOLO Taxonomy:

- analysis of the prerequisites: know Ohm’s law, Kirchoffs laws, and Equation system at a **Relational** level
- rephrasing of the intended learning outcome:
  - reach a **Multistructural level** connecting the consequences of negative feedback for the voltage on the inputs with $U_{UT}(U_{IN})$ where U_{IN} is the difference of the voltage inputs on + and –

Reformulation according to Feisel-Schmitz Technical (FST):

- analysis of the prerequisites: be able to **Explain** Ohm’s law, Kirchoffs laws, and Equation system
- rephrasing of the intended learning outcome:
  - be able to **Compute** the consequences of negative feedback for the voltage on the inputs;
  - be able to **Explain** $U_{UT}(U_{IN})$ where U_{IN} is the difference of the voltage inputs on + and –

3.3 Summary of the reflections for the different taxonomies

Reflections on using Bloom’s Revised Taxonomy (BRT)

Strengths: Being quite famous, there exists quite some material about this taxonomy; this means that it is feasible for teachers to look for aid in interpreting the verbs defining the various taxonomy levels. Also, it is likely to be included in teacher training courses due to its popularity and widespread use.

Weaknesses: Analysing relevant intended learning outcomes using Bloom’s notation was generally experienced as difficult and arbitrary. Specifically, the level “*understand*” puzzled some of the instructors of the courses above. We note that in Bloom’s original work he used “comprehend” instead, which might make some sense why we experienced that “understand” should (could) be at a higher level in the Cognitive process dimension. On top of this, ”evaluate” was considered below “*apply*” as another example. To put it simple: the number of verbs (and its hierarchical order) was confusing the teachers. The main problem experienced with this taxonomy can be thus summarized into its unsuitability in handling progression in content. This makes it hard to build “as-is” in Higher Education (a result that is in line with Brabrand and Dahl 2009).

Reflections on SOLO taxonomy

Strengths: The levels are clearer than for the BRT, and they are perceived as capturing progression in a course in a more natural way. The taxonomy is perceived moreover as helping connecting different learning environments (i.e. TLA's) with the various intended learning outcomes. We also note that the various instructors perceived that to reach the Qualitative phase having a clear intuition of the context surrounding the TLAs and intended outcomes became more important.

Weaknesses: The descriptions of the levels are perceived as rather abstract, which makes it hard to get a consistent categorisation among different teachers. The perception is also that this taxonomy is not easily applicable for non-operational competencies (communicative and activities), and thus that it is not easily applicable to non-cognitive outcomes. Like the BRT, thus, this taxonomy suffers in capturing progression in content and does not consider the prerequisites.

Reflections on Feisel-Schmitz Technical taxonomy

Strengths: All the teachers of the courses above perceive the levels to build up on each other in an intuitive and clear way. As noticed also for the SOLO, many of the learning goals are reached on a low level (perhaps too low), which helps the teacher realise how to improve the course descriptions (and the course itself). The taxonomy is perceived as much more appropriate to describe engineering education; for example, engineering teachers can relate immediately to the fact that one can compute something without being able to explain it. Another positive side of this taxonomy was the fact that it was possible to define the levels independently from the definition of the prerequisite knowledge.

Weaknesses: Some levels seem to be dependent; more precisely, *Explain* & *Judge,* and *Compute* & *Solve*. The common opinion of the teachers was that the *Judge* should be seen as a more complex version of *Explain*, while *Solve* should be a more complex *Compute*. However there was some discretionality in the intuitions of the teachers, making it almost impossible to distinguish the levels of learning in an objective way.

3.4 Concluding remarks

Somewhat surprisingly, the Knowledge dimension of BRT very much resembles the Feisel-Schmitz taxonomy: Define / fact; Compute / procedural; Explain / conceptual; Solve, Judge / metacognitive. On the one hand, this points to contradic-tions and conflicts between the two taxonomies (in the sense that FST should in principle be mapped to the Cognitive Process dimen-sion), and on the other hand it feels natural that specific categories of knowledge objects and mostly associated with specific levels of cognitive skills. Further, none of the taxonomies is specifically devised for the special environment of the intended learning outcomes of the courses above. Additionally, the above reflections highlight the relevance of the disciplinary domain in formulation of learning outcomes, which lacks in BRT and SOLO whilst FST makes it more intuitive and clear for teachers to use it in their technical fields - this is probably related to which conceptual meaning verbs have and what they enclose in engineering practice. In sum, a taxonomy for engineering education needs also to be contextual, i.e. relatable with 'language' and practice. However, such FST is not without limitations, namely in showing the hierarchical levels of learning and non-cognitive outcomes. In conclusion, it is needed to develop a taxonomy that brings together the strengths of the three taxonomies and includes the non-cognitive, transversal skills that 30 years ago were not perceived relevant to engineering education. Furthermore, the limitations of the taxonomies also affect in which ways PBL is integrated in the courses, namely the difficulties in designing activities which would be student-centred, and which would be teacher-centred. Consequently, other curriculum elements such as type of facilitation, problems and learning progression would also be challenging to define. In sum, taxonomies pose limitations in defining which PBL approach would be more suitable for a given course, its learning, to create a coherent and aligned curriculum, both in its written form (i.e. course descriptions), operationalised (i.e. what teachers do in practice) and experienced (i.e. what students experience in practice)forms.

4 Conclusion

Although the paper addresses one or two courses from different programmes, there is a clear strategy on how to build curriculum coherence since the coherence start with building up the hierarchy within the courses from the prerequisites (from earlier courses), and how the learning outcomes become prerequisites (or graduated expertise) for later learning outcomes and courses. This bottom-up approach comes from the decided fact that the programme learning goals are established and broken down to courses and their learning goals.

As a premise, we note that none of the taxonomies was developed considering the specific environment of the courses. All the authors agree that the FST is the most intuitive and useful in categorizing and describing the intended learning outcomes of the considered courses. However, adding these taxonomic descriptions did not significantly help making the learning activities more student-centred or PBL oriented. This is deemed to be due to the difficulty of connecting the different learning outcomes with learning activities and environments. Therefore, a common perception was that using a taxonomy for classifying, improving and rewriting the intended learning outcomes may benefit from some generic extension that enables to connect the learned content to its place in the curricula of the course/program (probably most importantly the program).

The developed intuition is that to promote deep learning and synthesizing effective PBL activities there is the need for taxonomies that are effective in revising and complementing courses. The envisioned taxonomy should nurture the progression of the program where teachers see how their taught knowledge is used in a further context, and in this way promote collaboration possibilities as themes, problems or project based, also within the teaching body.

The discussions around the creation of this manuscript led also to thinking at the following future works: how can we guarantee a method for investigating curriculum coherence? The intuition is that capturing cognitive abilities is easier than capturing non-cognitive ones. There is thus the need for taxonomies (and associated workflows) to express non-cognitive learning outcomes as transversal skills. It is the authors' belief that the envisioned taxonomy and workflow shall be clear, non-interpretable, and making sense in a self-standing way.

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Promotion of competencies through case studies in logisticsstudies

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Abstract

With the aim of promoting competencies for professional practice, the "Logistics - Diagnostics and Design" (LDD) study programme at the University of Applied Sciences in Kaiserslautern is using problem-based learning methods which include teaching with case studies.

Case studies offer the opportunity to put students in a work place environment. With our approach of case-based teaching, the state of a company which is to be analysed is described in more detail by teams of students. With the help of analysis methods from consulting, they deduce the underlying problems of the case and then develop solution concepts. The results of the process are presented by the teams to the lecturer - the clients and examiners - and the fellow students. The module is characterised by the fact that the students have to adjust to different clients who have different focuses and are experts in different areas of logistics.

Despite the practice-oriented teaching, the students have difficulties in transferring their approach to other case studies or projects.

In order to support the students in this transfer, the procedure model "Model B" was developed at the University of Applied Science Kaiserslautern for the efficient processing of case studies. The model is characterised by eight steps and was set up on the basis of procedures from PBL didactics and logistics. The students can work in a structured procedure up to the results and this approach is transferable to other projects.

Competencies are enhanced, including the ability to solve problems through a structured approach. The “Model B“ empowers the students to adopt a disciplined attitude and efficient performance. The case-based teaching of the university promotes professional self-understanding and competencies.

Keywords: Case Study, Problem-based Learning, Engineering, Projects, Transfer

Type of contribution: PBL best practice

1 Introduction – embedding in the study programme

Logistics experts plan, manage and control material and information flows. They operate in partnership with colleagues, customers and suppliers in all areas of the economy. Especially and good coordination make target-oriented solutions a possibility. The study programme “Logistics - Diagnostics and Design” (LDD), the students are capable to manage logistics challenges and at the same time have a consulting function in which they think and act according to goals of the company. In the study program LDD students learn both - the art of finding the "real" problem in logistics and designing the "right" solution in interdisciplinary teams.

Graduates should be team players and be considerate. They should also have a strong interest in finding solutions and act pragmatically and efficiently. The main goal of the study programme is "employability", which is achieved by training project orientation, team skills and professional competence. (University of Applied Science Kaiserslautern, 2012) These main goals motivated the design of the course “Case Studies - Diagnosis and Design” in the sixth semester. In the previous semesters, students have already been trained in specialist knowledge as well as in other competencies requiring being personable. They are familiar with problem-based teaching methods preparing them for the working environment.

Zumbach’s publications have shown how problem-based teaching can be implemented pedagogically into courses of study. In the courses using PBL, the students comprehend texts, apply the text to target groups, research key points of literature, prepare presentations and hold consultations with lecturers while independeently organising the group work (Zumbach, 2003). This foundation was used for the implementation of problem-based learning into the logistics course of studies.

The students work on projects in modules such as STEM-lab in which they understand fundamentals of science, technology, engineering and mathematics by conducting experiments under PBL. In “Team and Conflict Management” students reflect on their personal ability to work in a team and learn about communication and conflict resolution models. In “Studium Generale”, students become involved in civil society through a combination of workshops and practical work in social, cultural or ecological institutions. In “Design of Logistical Processes” students learn about general problems by transferring methods and procedures to logistical problems. The module "Logistical Data Analysis" allows teams of students to analyse and evaluate complex data sets by working with data in a practical and problem-based manner.

This knowledge and the improvement soft skills have to be accessed to the full extent in module “Case Studies - Diagnosis and Design”. In this course, teams work on several problems, given from different lecturers in the role of clients. Teams must react to different problems and cases, which requires a high level of cooperation and flexibility. This allows students to work on logistical problems that occur in complex situations realistically. Than teams will be assessed and examined on their presentation and their client-oriented solutions.

Students discuss and diagnose the "real" problems that lie behind the described cases. For this purpose, they analyse requirements of logistics systems and check potentials for improvement. The students coordinate the best client-oriented solution from the many possibilities. However, this solution must also be acceptable and economically viable. They balance technology, information technology and business administration and design the "right" solution. They are intensively involved in a topic, can apply the knowledge they have acquired during their studies and at the same time practice what they need in projects and daily professional routine. In doing so, they also improve teamwork and become more confident in presenting solutions. (Wölker, 2014)

The description "right" comes from the description of the logistical order in logistics science. According to this, at the point of order fulfillment the purchase order contains the right product delivered at the right time to the right place in the right quantity and right quality at the right cost. Therefore "right" means in the way the customer's order is given (Jünemann, 1989).

2 Orchestration of the module and behaviour of the involved stakeholders

Rather than merely accumulating technical expertise without suitable application, students are trained how to behave as logisticians in different scenarios. In combination with small projects, students train their ability to plan, manage and control projects. The students have thus learned to organize teams autonomously, keep deadlines, and ensure that all necessary tasks are carried out. This concept is refered as problem and project based learning (p²bl) at the University of Applied Science Kaiserslautern.

2.1 Case-based teaching in PBL

As a problem based teaching method, the case study is characterised by the dialogue between teachers and students, which distinguishes it from the classical lecture. The case study has its origin at the Harvard University in America. The case method was first used in 1870 under Langdell (Langdell 2004).

The case analysis should be seen as the equivalent of the medical "second opinion". In medicine, data about the condition of a patient is collected and from this data the case history is created, which collects the current symptoms, family background and environmental influences. In addition, general information, such as vital signs, is collected. Based on the case history, a diagnosis is made and the appropriate treatment is initiated. If the patient doubts the correctness of the chosen measure, he will consult other physicians to repeat the procedure (Bonoma, 1989).

A case in logistics studies is a description of a management situation. Applied to logistics, a case study is a situation in which a consultant looks at a company and recognises problems through discussions with the management. For the “second opinion” the consultant then creates the case history from current problems, the historical background, and current environmental influences, such as globalization or demographic change. Furthermore, he has to analyse the collected data and, if necessary, collect further data through observations, interviews or measurements. From the case history, the diagnosis is made and solutions are designed, for whose implementation measures are formulated in the form of work packages.

Particular importance is attached to the fact that students do not work through instructions, but recognise what needs to be done by themselves. The special features of this implementation of case-based teaching are the setting, which brings together different clients and thus orders in one module, and the process model, which was specially created for the transfer to projects in logistics.

2.2 Setting of the module “Case Studies - Diagnosis and Design”

Since there are many stakeholders in this module, everyone must be assigned a clear role. To ensure this, situation, a setting is needed in which the roles of the many actors are clarified. The module manager accompanies and advises the students throughout the semester. The module manager acts as the senior consultant and examiner for all the cases, additionally taking the role of the client in one case. In modules from previous semesters he often acted as coach or mentor. In this module he is placed in the professional role of a senior consultant.

The lecturers, acting as clients, either write down the case or describe it orally to the students. Lecturers will only be involved again when students have questions for them. The lecturer decides whether and how detailed the questions are answered.

The module manager, acting as the senior consultant, brings much experience working on projects and knows what needs to be considered when proceeding. He is not present at the presentation of the case by the client, but accompanies the students while solving the case. He meets with the students once to review their first results from self-study. If necessary, he gives advice on the general procedure or encourages discussions between the teams.

The student teams take on the role of junior consultant teams. They have little or no experience with real projects or case studies. After receiving the case from the client the teams must report to the senior consultant about the case.

The procedure for each individual case is as follows:

- the client (role of the lecturers) describes the situation of his fictitious company to the students
- the junior consultants (role of the student teams) identify the underlying problem of the situation in self-study
- the junior consultants describe the situation and problem of the client to the senior consultant (role of the module manager)
- the junior consultants discuss their different interpretations among themselves and the senior consultant gives advice where necessary
- the junior consultants consider possible solutions, derive measures and assess the effects in self-study
- the junior consultants present their results to the senior consultant and the client and make a recommendation for action
- the client and the senior consultant evaluate and examine the presentation

2.3 Procedure of the students - Model B

At the University of Applied Sciences in Kaiserslautern lecturers have experienced that students have little motivation to read very long instructions and then implement them adequately. For this reason, it was out of the question to create a manual but a practicable alternative was required. For this reason, it was out of the question to create a manual but rather a practicable alternative was required, allowing the students to get to work quickly.

Although the students know process models from logistics, they do not apply them to the case studies. The students got to know these models in the fifth semester. Therefore, we recognised the need to draw from models in didactics, logistics and case-based teaching and to offer a practicable approach with a new model. Although they are able to identify projects and know procedures through their studies, they could not systematically work on case studies in the past. Since the students could not transfer the procedures of models from didactics to professional life, it was out of the question to use them in the module. Because the students did not apply the models from logistics, the models needed to be adapted for teaching purposes. As other universities also use case studies, procedure implemented at Harvard University, for example, was taking into consideration. These three pillars were the foundation for our own process model “Model B”. (Müller, 2019)

The process model Pirmasenser 10-step is designed to provide assistance in solving problems, adapted from the 7-step method of PBL (Daggett et al., 2017). The students familiar with the 7-step method and use it. The Pirmasenser 10-step derived from it is used by the students in STEM-lab I and II. In the further course of their studies the students apply these models for problem-based learning. Recognising, that this model do not appropriate address the process in the system of the case studies in “Case Studies - Diagnosis and Design”, a research was done which model might be usefully for the students and the requirement of the case studies.

As an example of a procedure model for case studies, the procedure of Harvard was considered, since this university has a lot of evidence for case-based teaching. At Harvard University, students read the Case Study Handbook, which explains in three phases how to proceed into case-based teaching (Ellet (2007). In the first phase, analysis, students read the description, then list questions about the situation, form hypotheses and develop options for action. They then take a critical look at their own solution once again. Then the students meet with the lecturer at the university. The lecturer moderates the second phase, the discussion. The handbook contains rules of conduct for the students during this phase. Afterwards, they write an essay in self-study in which they explain their position, how they came to their decision, and how they want to reach the target state with the help of an action plan.

Next, a model from logistics should be considered, with which the modeling of logistic systems is planned. The phase classification of planning, according to Furmans and Arnold, says that before analysing the problem, it is necessary to first recognize the problem. After that, the target is commited. Then follows the forecast of the development and possible alternative must be found. Finally, the alternatives are evaluated, and a decision is made (Arnold D. et al., 2008).

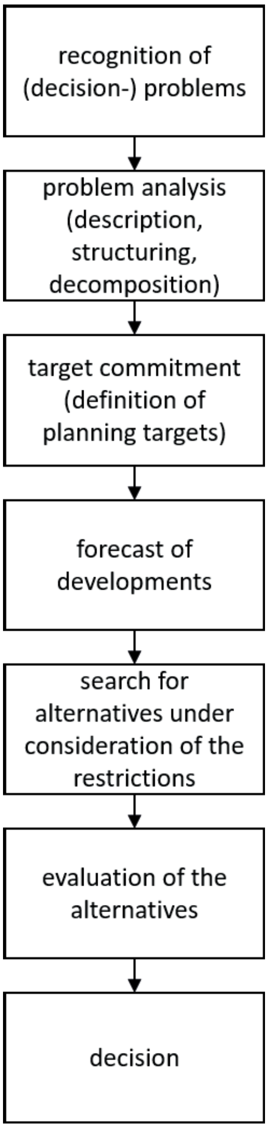

Figure 1: Illustration of the phases of a planning process according to Furmans and Arnold

The model were created for logistics projects but offer a general procedure for dealing with logistical tasks. The transfer to real projects would therefore be easier with these models, but it is questionable whether the application for case studies will be successful.

If the learning objective of our case studies is defined as the promotion of action competence for logistic projects, the process model should not aim at supporting case solutions, but at training general procedures.

Therefore, at the University of Applied Sciences in Kaiserslautern a process model was developed. The components of the model are shown below.

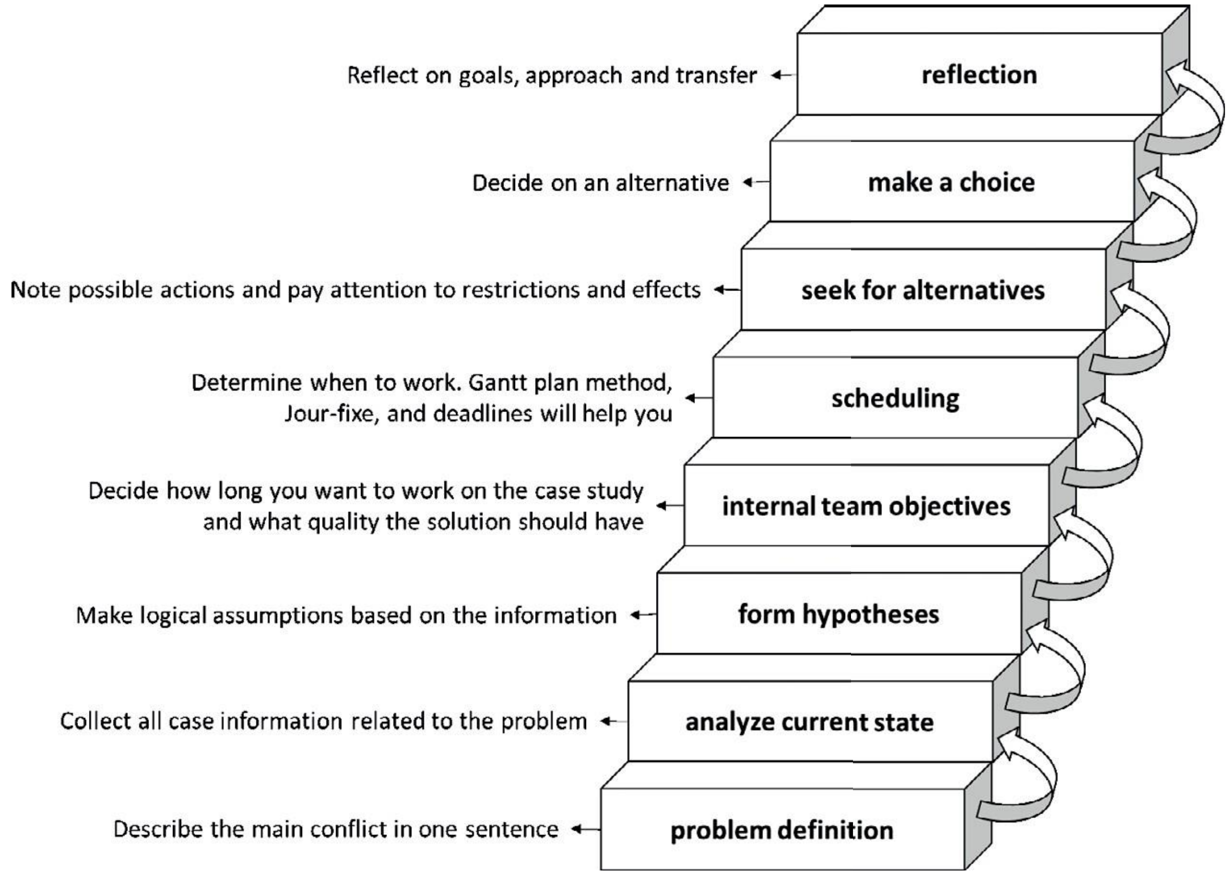

Figure 2: Illustration of the procedure model Model B according to Müller

After recording the situation described by the client, the problem has to be recognised and defined. The teams discuss different approaches to find the problems and and possible conflicts associated with them. “Problems and their solving are in the context of the person who subjectively addresses the problem.” (Wölker et. al., 2017).

This is followed by hypothesising, i.e. a logical assumption based on the previous work, which is to be checked later. At this point, no further research is to be started, as the team-internal goals for further work have to be defined first. Team goals relate to the time spent on the case study, the work to be done during this time, and the quality of the solution.

Ensuing teams make the time planning for the case study. After clarifying how much time will be spent, the Jour fixe and Gantt plan tool will support compliance. Deadlines help the team to solve the task together on time, despite having differing individual schedules.

Once the planning is complete, alternatives for solving the problem are worked out. Attention must be paid to restrictions and effects of the alternative solutions. A commitment made too quickly to a solution can inhibit the creative process which can realize other possible options. For this reason, no decision should be made at this point. Only when all alternatives with restrictions and effects have been worked out will a decision be made. This must be accepted by the whole team, as it will be presented later and may have to be defended.

The students have two weeks for the whole process. The time span and the overlapping of several open cases should show the project aspect in the p²bl. When meeting the module manager, the teams must have completed the "scheduling" level.

2.4 Procedure of the lecturers - continuous improvement process

Six lecturers of the logistics department form a team for the module. Each individual acts as client and examiner for their own case. The module manager is also the senior consultant and second examiner of all cases.

The lecturers introduce cases different from their professional practice. For this reason, the cases are very realistic and the lecturers can also provide important impulses if required. Although only the module manager is present during the work, the lecturers are open to questions from the students. The lecturers are also open to different creative solutions of the students. Even if they know the real solution, they discuss new ideas with the students. The lecturers do not supply a sample solution.

It is extraordinary that six lecturers work together as a team in one module. This requires special organisational coordination and respectful interaction. Without the lecturing team, it would not be possible to show the students the different roles clearly and to make the different interests of clients clear.

The fact that the lecturers have different interests is partly due to personal taste and partly because they come from different disciplines in logistics. For the client-oriented solution the students must always be aware of the interests of the lecturers. Nevertheless, they also have to find the solution to the present problem of the case. The module manager, who is present at all assessments, puts, to the best of his ability, his own interests aside. The decisive factor for a good solution is whether it fits the client and its case.

The lecturers are open to the students' solutions, but the presentation must be logically structured. While it is not so important to recount the initial situation in detail, it is important that the students show their methodical approach to the work. The exact order of the cases and the combination of pairs of cases for oral examinations and cases for homework are also being worked on.

3 Evaluation

In the winter semester of 2017/18, Model B was developed and implemented in the module. In the spring semester of 2018, the students underwent an evaluation which intended to show whether the students could apply the model and whether they could use it for real projects. The answers could range from 1-5, with 1 corresponding to “applies” and 5 corresponding to “does not apply at all”. Of 18 students, four fully agreed with the statement "Procedure model has supported planning and procedure during the case" and five gave a value of 2 for agreement. Two students fully agreed with the statement "I can use the model for real projects", four students gave a value of 2 and three students gave a neutral value.

In order to receive feedback from students, the evaluation of Model B was carried out. The monitoring of the elaboration of the students was much more structured than in the previous year. Using a structured approach, the students were able to work together and ask questions to the senior manager. In addition to that with each new case study in the module, the students became more experienced in the application and discussion in the classroom.

Some students reported back after completing the module that they had used Model B for their bachelor thesis in the seventh semester.

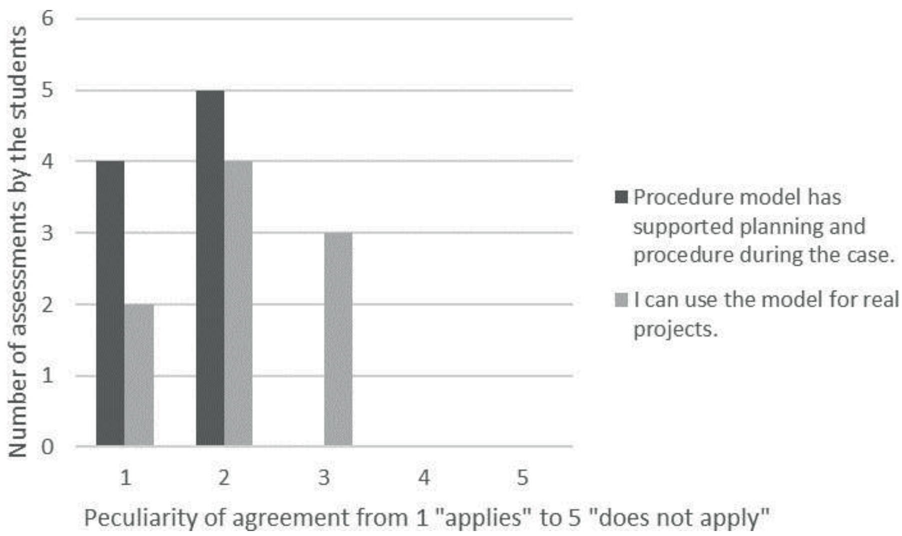

Figure 3: Results for Model B from the interview with students of the module

4 Employability and competencies in "Case Studies - Diagnosis and Design"

Important learning goals in the course of studies "Logistics - Diagnostics and Design" are employability, competencies and the creation of a professional self-understanding. The module "Case Studies - Diagnosis and Design" in the sixth semester creates a scenario in which students are trained in various competencies through setting and approach of students and teachers.

Employability is achieved when the students have developed the professional self-understanding of a logistican, who is able to scan and record the client's order first. After that logisticans elaborate the spectrum of possible actions, make a decision for the right solution and create and hold an adequate presentation of it. The achievement of employability requires the training of this attitude in teams. It is not enough to inform the students in lectures about this way of working. In the module they have the opportunity to sharpen their professional self-understanding by learning with case studies.

By learning with the case studies, students train to independently recognize and describe problems in unclear situations and to solve them afterwards. This is an important skill in the field of logistics, as they often have to optimise systems or, when setting up new systems in the context of a project, have to recognise problems in old systems in order to avoid them in the new system.

Because of the setting with the six lecturers, students in case-based teaching get used to working not only order-related but also client-related. On the one hand, this means knowing the client's interests and ideas, but on the other hand it also means finding the right solution and presenting it in a goal-oriented way. A transfer of this approach to other disciplines and study programmes is possible.

Since receiving the case of one lecturer and presenting the solution to another lecturer during the semester partly overlap, students have to react flexibly to the different clients. In addition, they also have to answer questions from the module manager, although the presentation is mainly client oriented.

The organization with junior consultants and senior consultants is based on the professional reality of logistics consultants. The fact that the senior consultant is not present when the case is received by the junior consultants trains students to report to the senior consultant with their developed goals. With his feedback in the face-to-face session, they train how to deal with superiors.

Since students only have two weeks to complete a case study and there is an overlap between receiving a case from one lecturer and presenting the solution to another lecturer, students are forced to create schedules. The Model B process model for students also requires them to create a schedule with Jour Fixe and deadlines, for example using the Gantt plan method. The students thereby practice working in teams under time pressure.

Dealing with the module manager, who acts simultaneously as client, senior consultant and examiner, is a challenging task for the students. Depending on the phase of the case study, they have to communicate with the module manager on a personal and role-related basis.

Since each team gives a presentation of its solution for each case, a large number of presentations are held in the module. Students therefore often have the opportunity to improve their presentation competencies and get feedback from examiners and fellow students. They are taught how to use presentation media and how they act themselves and as a team.

5 Conclusion and lessons learned

The further development of the module is necessary, as well as the further development of all modules of the study programme "Logistics - Diagnostics and Design". The special challenge in this module is to manage the cooperation of the lecturers as a team. Preparation, implementation as well as critical reflection with appropriate communication as a team are prerequisites for improvement.

The reward for this continuous improvement is that the module is often mentioned by students as one of the most exciting modules in logistics studies. A direct comparison of the modules within the framework of an evaluation would certainly be interesting for the development of logistics study programmes.

Feedback from students from the practical semester has shown that the students apply the developed process model Model B in the companies. This feedback confirms, by way of example, the possibility of transferring the model to everyday working life. At the end of the module, the students usually confirm in question and answer sessions that they feel well prepared for the practical semester.

The module is the logical conclusion of a course of study that works with many problem-based modules. Students have trained to work flexibly with the help of PBL in all semesters. The setting of the module has sensitized them to client-oriented work, a skill they need especially as consultants but also in general in optimization projects in logistics.

The special setting always places new demands on the teams, which means that they follow the event very attentively and can contribute different strengths. This makes it possible for a different team member to be an expert for each case. The change of environment keeps the students' tension from the beginning to the end of the semester.

The lessons learned from the project is that students need a structured and practical approach. By repeatedly using Model B, they become more confident in dealing with new situations with different stakeholders.

In project work, we aim to promote cooperation with companies, but according to the experience of the lecturers, they must learn professional behaviour in a protected environment. There is no grading in the assessments in order to allow students to make mistakes during the processing of the cases and learn from it. Only in the oral examinations they have to show that they have sufficiently trained the professional behaviour. The lecturers make sure that the requirements are sufficiently transparent and give constructive feedback on the student results.

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Designing Progressive Intended Learning Outcomes for PBL: A Workshop Format for Curriculum Redesign

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Abstract

Generic competences such as teamwork, communication and system thinking have gained increasing attention in engineering education, and problem-based learning (PBL) models have been highlighted as effective in fostering such competences. Aalborg University (AAU), Denmark, has had a systemic approach to PBL since its foundation in 1974, and in 2018 a process was initiated to make the progression of PBL competences more explicit in the curricula. Consequently, all study programmes had to redesign their curriculum and integrate progressive intended learning outcomes (PILOs) for PBL. In the engineering and science faculties, a project was initiated with the purpose of supporting all study programmes in the process of designing such learning outcomes. The outcome was a guide for staff to develop PILOs for PBL, presenting a participatory process design and a complementary workshop format. This paper outlines the process for educational design, the workshop format, and reflections on the project carried out at AAU as a best practice example of integrating PBL throughout the curricula in an inclusive and participatory way.

Keywords: progression, problem-based learning competences, curriculum development

Type of contribution: Practice paper

1 Introduction

Generic competences such as teamwork, communication and system thinking have gained increasing attention in engineering education to cope with the ever-changing and increasingly complex societal challenges. As noted by Graham (2018, p. 39), based on a study of leaders in engineering education, future engineering curricula will “emphasise student choice, multi-disciplinary learning and societal impact, as well as expose students to a breadth of experiences outside the classroom, outside the traditional engineering discipline and across the world”.

Problem-based learning (PBL) models have been highlighted as effective to foster generic competences alongside domain-specific competences (Kolmos & Koretke, 2017), and PBL models in different shades have been implemented worldwide. However, where there is not much doubt that PBL is seen as an effective means to foster domain-specific engineering competences, it is more questionable whether PBL competences are acknowledged as an end in themselves that are worth emphasising in the explicit curriculum. Aalborg University (AAU), Denmark, has had a systemic approach to PBL since its foundation in 1974, and PBL has been an integrated part of the curriculum from the very beginning. In the first year, students are assessed in their achievement of certain PBL competences; after the first year, however, there is no further focus on this (Kolmos, Bøgelund, & Spliid, 2019).

In 2018, as a part of the institutional strategy, AAU management initiated a process to highlight the progression of PBL competences in the written curriculum. Consequently, all study programmes had to redesign their curriculum and integrate so-called progressive intended learning outcomes (PPILOs) for PBL throughout the curriculum for PBL, with a clear progression and employability perspective appropriate to the specific educational profile.

At the Technical Faculty of IT and Design (TECH) and the faculty of Engineering and Science (ENG), a project was initiated with the purpose of supporting all study programmes in the process of designing such PILOs. However, for many of the programmes, the progression of learning objectives was far from explicit after the first semester, and even though students saw a progression in PBL competences, it was more implicit than explicit in the curricula (Holgaard & Kolmos, 2019).

The ambition was to frame the process, but to leave the sensemaking and formulation of PILOs to the staff actively involved in the programmes and responsible for supporting students' learning in the specific educational context. The outcome was a guide for staff to develop intended learning outcomes (PILOs) for PBL in a participatory design and workshop format. The workshop format is based on a card game, where the cards have the sole purpose of initiating dialogue in a workshop setting.

This paper outlines the process for educational design, the workshop format, and reflections on the project carried out at AAU as a best practice for inclusive and participatory educational design of progressive learning outcomes for PBL.

2 Sources of inspiration—theoretical as well as experience-based

Holgaard and Kolmos (2019) characterise different types of PBL competence in four types: problem-oriented, interpersonal, structural and metacognitive. These four types of competence cover the intentions in the AAU PBL principles (see AAU, 2015). As illustrated in Figure 1, metacognitive competences are cross-cutting. Metacognitive competences raise the other competences above the level of application in Bloom's taxonomy (Bloom, 1956), enabling students to analyse, evaluate and synthesise their approach to learning to address new modes of application. As such, without this cross-cutting competence, the other competences are reduced to skills.

In the TECH and ENG faculties, all students have a course of five European Credits (according to the European Credit Transfer and Accumulation System - ECTS) in the first semester on problem-based learning in science, technology and society (Kolmos et al., 2019). This course creates the basis for students to practise PBL, and supplements the problem-based project work supported by facilitators from the disciplines. The problem-based project work is organised in teams and is somewhat extensive, as it takes up half of the study time in each semester. Furthermore, PBL consultants from PBL research environments scaffold the students to ensure that the students develop metacognitive competences.

The students document their metacognitive competences through a process analysis, three times in the first year, and with increased depth. The process analysis concept was developed in the late 1990s (Kolmos & Kofoed, 2002) based on the experiential learning theory, primarily with inspiration from Kolb (1984). However, systematic development of metacognitive PBL competences only takes place during the first year of study.

Figure 1: PBL competences as outlined in Holgaard and Kolmos (2019:1645)

The long-term experience of building students' PBL competences in the first semester has created the foundation for exemplifying the PBL competences in Figure 1. At the same time, it has formed the approach to develop PILOs for PBL throughout the curricula.

3 Implementation: process overview

Although ongoing curriculum development is common at Aalborg University, explicit focus on the implementation of progressive PILOs for generic competences like PBL has been rare, and therefore the implementation process design had to be developed. At the faculty of Engineering and Science and the Technical Faculty of IT and Design, deputy deans managed the implementation process in close collaboration with the Aalborg Centre for Problem-Based Learning in Engineering Science and Sustainability under the auspices of UNESCO (UCPBL). The pro-deans clarified that the overall framework should rely on a participatory process, while the programme managers and practitioners were the ones to outline the learning objectives based on the overall AAU framework for PBL competences (see section 2). UCPBL was not therefore the designer of a set of PILOs for PBL to be integrated into the curricula of all programmes. On the contrary, they served as process facilitators to frame the process, as well as to inspire and support local research communities to take ownership of the design process of new PILOs for the curricula.

For the local educational communities, the presence of PBL in the curricula was not totally new—for one thing, due to the learning objectives in the PBL course in the first semester. Therefore, the process first of all included consideration of the PILOs for PBL that were already included in the curricula. Secondly—and as research has shown that after the first semester the progression of PBL competences is far from explicit—it is important to capture these tacit competences by considering activities in the programme with an implicit ambition of developing PBL competences, and to question whether this should be made more explicit in the curricula. Finally, staff should also consider prescriptive perspectives of the curricula in terms of emphasising PILOs pointing to new directions in future engineering and science education.

3.1 A five-phasemodel

To capture creative ideas to rethink PBL practices and to consider existing PBL practices being more or less explicit, the one-year process of implementing PILOs for PBL was designed in five stages (see Figure 2).

Figure 2: Outline of the process of implementing PILOs for the progression of PBL competences

Phase 1: Idea generation

To ensure that the discourse of PBL does not close around current ways of integrating PBL in the curricula or current practices, the process of designing PILOs is initiated by a phase of idea generation. The framing is made by a short introduction and a three-hour workshop for programme designers and practitioners. In the workshop, pre-prepared dialogue cards with aspects related to the four areas of PBL competences, as defined by the AAU PBL Academy, are used to point out important aspects of PBL within the particular programme (see more about the workshop material in section 4). Furthermore, staff are asked to structure the ideas in relation to the semester structure, having four semesters on the Bachelor programmes and four semesters on the Master programmes.

Phase 2: Reflection and diffusion

After the idea generation workshop, the PBL aspects mapped in relation to different semesters are used as what Wenger (1998) would call a boundary object for further reflection and discussion. It is recommended that the visualisations from the idea generation workshop are placed in the lunchroom, making space for an informal dialogue and offering easy access to add more post-it notes with more ideas. Furthermore, it is recommended that the results of the idea generation workshop be reported online, with the possibility for further additions.

Phase 3: Prioritising and framing

In phase 3, the ideas from phases 1 and 2 are gathered and the study boards (including both staff and students) have the important task of selecting the aspects of PBL which are to be stressed in the PILOs of the particular programme. Each programme has its own disciplinary scope, and it is the intention that the PILOs for PBL be aligned with this scope and integrated into relevant modules. Furthermore, and on a quantitative note, the number of PILOs for PBL should be balanced with the total number of PILOs in order to remain a strong core profile of the specific programme. Last but not least, the study board considers covering the four types of PBL competence.

Phase 4: Realising—from ideas to learning objectives

After key PBL aspects and derived ideas are selected for further development in phase 3, phase 4 supports the transformation from aspects/ideas to PILOs. Like in phase 1, a three-hour workshop format can be used to scaffold this process for programme managers and teaching staff, and again predesigned dialogue cards support the participants in the explication process. Besides supporting the formulation of PILOs for PBL, the workshop also helps faculties to prepare an outline for the corresponding teaching and assessment activities (see section 4 for further information).

Phase 5: Specifying

In the final phase, the study board refines the learning objectives developed in the workshop in phase 4 to ensure both horizontal and vertical alignment in the curricula. The study boards are advised to get an overview of the PILOs for PBL for each module and for each semester. In this way, it is also possible for teachers in different semesters to know who to coordinate with to ensure clear progression and coherence in the support students get to develop PBL competences progressively throughout their study.

3.2 Reflections on the overall process

The five phases presented in the previous section were prepared as an implementation guideline. The decision to guide and not direct proved to be beneficial for creating ownership—not only for integrating PILOs for PBL, but for the co-creation process beforehand. The local study communities were, however, obliged to report on their progress twice in the process. Even though the implementation of PILOs for PBL throughout the curricula is obligatory, the experiences from the facilitator of several workshops in phase 1 was that trust in the research environments taking responsibility for the process of implementing meaningful and aligned PILOs for PBL (instead of generic add-ons) created a clear motivation for change. Likewise, the pedagogical unit, UCPBL, supported the process with online resources and, on request, facilitating workshops and attending meetings. By no means did the pedagogical unit try to interfere with decision-making processes and the actual defining of the PILOs for PBL.

Another important reflection concerns the time management of the process. For some programmes, idea generation came rather late in the process due to other urgent matters, which put considerable pressure on the last phases of the process. We saw on some occasions that phases 2–5 merged, and the focus on delivering PILOs as requested to some extent overpowered considerations of progression and coverage. Therefore, progression and coverage should be properly considered in the subsequent process of evaluating and eventually qualifying the implemented PILOs for PBL. At AAU, this process is set up as a cross-university activity, where study boards receive feedback from the PBL Academy on the result of the implementation as it presents itself in the revised curricula.

4 A workshop kit for initiating PILOs for PBL competence

To scaffold the process of implementing PILOs for PBL throughout the curricula, the UCPBL developed a so-called workshop kit for staff (related to phases 1 and 4). The workshops could be facilitated by UCPBL on request, but it was also possible for local faculties, through the use of online resources, to facilitate the process themselves. The workshop setting was considered important to benefit from the group creativity taking place in face-to-face discussions. As noted in the previous section, the workshops at AAU were structured in two sessions as a part of an overall implementation plan, but the overall aim was to get people together and facilitate them to address the following five questions:

- What are the core PBL aspects in the particular programme?
- When should we (re)visit these PBL aspects in the curriculum?
- How do we transfer aspects of PBL into qualifications?
- How can we support students in reaching the intended PBL qualifications?
- How do we assess the PBL qualifications?

The core of the toolkit is dialogue cards, which are developed with the sole purpose of initiating dialogue. The purpose is therefore not to present a complete overview of aspects related to the PBL competence; on the contrary, ideas can emerge by noticing what is not present. To stress this, sets of dialogue cards are always in pairs of 12, this number being chosen as cards can easily be divided into subgroups of two, three or four, according to preference.

In the following, we elaborate on the reasons for asking these particular questions in designing PILOs for PBL, and the toolkit provided to support staff to address these questions.

4.1 What are the core PBL aspects in the particular programme?

The process was initiated by referring to aspects of PBL instead of PBL qualifications, to detach the first line of thinking from the learning situation itself. Instead, the intention was that staff would start to consider what it is valuable for candidates within a given engineering or science profession to know about and bring into practice. Four sets of 12 PBL aspects were presented on dialogue cards, respectively related to the problem-oriented, interpersonal, structural and metacognitive competences. The aspects chosen to initiate dialogue in the AAU case are shown in Figure 3.

Figure 3: PBL aspects used to initiate dialogue in relation to the four types of PBL competence

The cards were of different colours; for each colour, the assigned group was handed post-it notes in corresponding colours. The idea was that the group, whenever possible, should specify the generic concepts on the dialogue cards by considering the given educational context. For example, the card drawing attention to problem analysis could generate three blue post-its, including actor network analysis, state-of-the-art analysis, and user needs in context study. In other cases—for example, for process analysis—a yellow note could specify that an analysis of project management, collaboration and learning processes is expected.

In the workshop sessions, groups worked with one colour at a time: thinking blue, thinking pink, thinking green and thinking yellow. Approximately 45 minutes to one hour per area is recommended for this brainstorming session. In most workshops, the competence areas were divided between workshop participants, so that everyone could contribute to the following phase 2.

4.2 When should we (re)visit these PBL aspects in the curriculum?

The identified and specified core PBL aspects of the programme are then related to semesters, focusing on vertical alignment in the curriculum and competence development. For this purpose, a pre-printed outline of semesters was handed to the participants to fill in their ideas/post-its, considering the alignment between the PBL aspect and overall semester aims, as well as patterns of progression.

A hypothetical example could be that agile management is related to SCRUM in the software engineering programme. Participants relate the development of SCRUM competences to semesters 1, 4 and 5. They have in mind that students in the first semester are taught and use selected techniques from SCRUM; in the fourth semester, they have an extended course on SCRUM to build up conceptual knowledge and skills; and in the fifth semester, they document their competence in project management of software development projects by using SCRUM.

12 active verbs to transfer from PBL aspects to PBL qualifications:

1. Plan...
2. Conceptualise...
3. Analyse...
4. Contextualise...
5. Exemplify...
6. Experiment with...
7. Create...
8. Optimise...
9. Evaluate...
10. Reflect on...
11. Discuss...
12. Transfer...

Figure 4: Verbs to initiate formulation of PILOs

4.3 How do we transfer PBL aspects to qualifications?

In the next phase, the chosen PBL aspects are transferred into the mindset of the european qualifications framework for lifelong learning (European Communities, 2008), classifying the knowledge, skills and competences related to a given aspect. Among others, Grün et al. (2009) highlight the strength of using active verbs as descriptors of knowledge, skills and competences. To initiate dialogue about the qualifications based on the PBL aspects, the 12 verbs in Figure 4 were proposed and transferred to dialogue cards.

As an example, if team culture is stressed as an important PBL aspect, it makes a difference whether students are required to conceptualise a team culture, to exemplify a team culture by use of personal experiences, or to optimise the team culture they are a part of in their group work. For the latter, the use of 'optimise' also indicates that the student can elaborate and argue his/her understanding of what an optimal team culture is.

4.4 How can we support students in reaching the PBL qualifications?

Along with the formulation of PILOs for PBL, staff have to consider how to su pport students in achieving the intended PBL qualifications. In other words, there has to be alignment between the PILOs and the pedagogical approach, including the planned teaching activities. In order to stimulate this discussion, 12 potential activities to support PILOs for PBL were pre-printed on dialogue cards to be discussed in relation to specific learning objectives (see figure 5).

For example, let us use an example where the ILO is that students can plan and manage problem-based project work

12 potential activities to support PILOs for PBL:

1. Facilitation of projects
2. Facilitating of casework
3. Online 'just-in-time' lectures
4. Inspirational speeches
5. Thematic workshops
6. Status seminars
7. Targeted feedback based on exercises
8. Excursions
9. Facilitation of cross-team collaboration
10. Facilitation of interdisciplinary collaboration
11. Facilitation of external collaboration
12. Ad-hoc individual coaching sessions

Figure 5: Activities to support PILOs

taking into consideration the given problem type, the team constellation and the duration of the project. In this situation, staff could, for example, consider a mix of:

- Inspirational talks on the diversity of real-life problems and ways to cope with this in project design
- Targeted feedback on students' project designs
- Ongoing attention to project design in the facilitation of projects
- Peer feedback in status seminars

4.5 How do we assess the PBL qualifications?

Last but not least, the PILOs for PBL and the pedagogical activities to support these have to be in alignment with the assessment methods. Yet again, 12 potential assessment approaches are noted on dialogue cards to open up a discussion of the appropriate assessment method in relation to a specific set of PILOs for PBL (see figure 6). First of all, the cards initiate a discussion of both summative and formative assessment methods. Secondly, they are designed to initiate a discussion about the type of documentation needed (individual or group-based) and, in line with this, whether the exam should be written (based on individual documentation) or oral (which might be based on documentation prepared in a group setting). Last but not least, they are designed to initiate a discussion of who the assessors should be.

12 potential activities to assess sets of PILOs for PBL:

1. Written exams documenting individual reflections on PBL processes
2. Written exams documenting individual casework
3. Oral exam where students are questioned based on shared process analysis
4. Oral exam where students are questioned based on shared casework
5. Pass/no-pass assessed by a certain extent of active participation
6. Integration of PBL in project exams
7. External examiners present at the assessment
8. Formative assessment in the group
9. Formative assessment of peer groups
10. Formative assessment across semesters
11. Formative assessment across educations
12. Self-assessment

Figure 6: Activities to support PILOs

4.6 Reflections on the use of the workshop kit

The workshop kit was made accessible to all studies across all faculties by establishing online resources with materials that could easily be adjusted to local needs—e.g. by changing the wording on the dialogue cards. There were only a few examples of revision of the dialogue cards, however. As an example, some included entrepreneurship as a problem-oriented aspect of PBL. However, faculties overall reported that the PBL aspects covered the intention to embrace different types of PBL competence in a way that worked across disciplines and educational programmes.

As noted in the following section, the idea generation workshop in the first phase was the most thorough, and therefore there is a lack of experience with the dialogue cards in the fourth phase. The experience from the idea generation workshop was that the dialogue cards worked well to initiate an engaged dialogue about generic competences, which for some seemed rather abstract at the outset. In the workshops facilitated by UCPBL, we as facilitators experienced that cards could also be characterised by the way the discussion was triggered, as different types of card within the same themes initiated different types of response.

The following types of card were distinguished:

- Cards creating a sense of familiarity—e.g. problem analysis, process analysis and teamwork are all embedded in the PBL way of AAU.
- Cards initiating a discussion about different perspectives on the same subject—e.g. the difference between distributed, situated and agile project management or different types ofassessment.
- Cards creating curiosity—e.g. questions like what is metacognition, what is active listening, what can be considered as different problem types, types of meeting, etc.
- Cards stressing the need for selective thinking when approaching a multi-directional concept—e.g. what line of thinking should we take to include sustainability, social learning theory or problem solving?

In changing the wording on the cards to fit local needs, it is recommended to pay attention to the need for diverse types of trigger to engage staff in co-constructing PILOs for PBL.

5 Final remarks

In this paper, we present a process of implementing progressive learning objectives for PBL, which can be adopted and adapted to local contexts. Furthermore, a workshop kit is presented in order to facilitate divergent thinking and open discussion of the content and prospects of PILOs for PBL. First of all, a comprehensive set of PBL competences were transferred into keywords on qualification cards. Different types of qualification card were presented, relating to four types of PBL competence: problem-oriented, structural, interpersonal and metacognitive. Secondly, activity cards were developed for staff to discuss the expectations of the taxonomic level of learning. Finally, evaluation cards were designed to consider the alignment between the PILOs for PBL and the assessment format. Last but not least, pre-printed overviews of semesters were designed to get an overview and ensure progression of PBL competences throughout the curriculum.

The process and workshop materials were developed for the Faculty of Engineering and Science and the Technical Faculty of IT and Design at Aalborg University, but made accessible for all faculties. The process has been designed with the aim of guiding and not directing the implementation of PILOs for PBL to create ownership and engagement for change. The next step is to evaluate, to disseminate experiences and outcomes, and to provide an opportunity to qualify the PILOs for PBL in the next round of revisions.
In this paper, the aim has been to disseminate the material even further to other university contexts, with the broader ambition of transforming engineering and science education to a stage of increased awareness, explication and enforcement of generic competences for PBL throughout the study, as well as on the subsequent professional path.

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Assessment Methods

Classification and framing in PBL: A Case Study

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Abstract

Problem-based and project organized learning is increasingly gaining traction as a pedagogical model suitable for supporting transversal competencies. Characterized by starting the learning process in authentic and exemplary problems, students at Aalborg University (AAU) engage in lengthy project-organized PBL often spanning an entire semester. The curriculum of each semester is organized in thematic blocks consisting of a large project supported by smaller individual disciplinary subject courses. The integration of the disciplinary subjects in the project is, is however, debatable. Answers from a survey distributed to 5th semester Medialogy students show that students found it challenging to integrate course content into their projects in the previous semester. Some students even found the course content irrelevant to their projects. In other words, a dissonance exists in the perceived relation between content presented in courses and content applied in projects. The situation has implored teachers to rethink the curriculum and pedagogy on the 4th semester of Medialogy.

Applying Bernstein's concepts of classification and framing as an interpretive framework to interviews with teachers and semester descriptions, we will analyze the classification and framing at this re-thought 4th semester. Classification conceptualizes the insulation between subjects and contents and framing the structuring of pedagogic communication such as pacing and sequencing. Specifically, we investigate how classification is described in the formal curriculum and in interviews with teachers. Further, we will briefly analyze how teachers reflect on the framing of the courses and projects. Bernstein's concepts of classification and framing appear to be useful when addressing the assimilation and levels of control of subjects and projects in project-organized problem-based learning.

Keywords: Problem-based learning, classification, frame, engineering education, Bernstein

Type of contribution: PBL research

1 Introduction

Introductions to research on problem-based learning (PBL) often hail the pedagogical model as an innovative approach to student-centered learning. The approach emphasizes student autonomy within a variety of confinements, be it structured problems or vast and complex possibilities of ill-structured, wicked, and interdependent fields of problems (Kolmos & de Graaff, 2013; Savin-Baden, 2014).
Central to the exploration is a social aspect where peers in groups of varying sizes inquire into specific authentic problems, some in a manner of weeks, others in months. Suffice to say, PBL exists in many different guises, all sharing some central components (De Graaff & Kolmos, 2003). Many of the learning activities unfolding in PBL are hidden from supervisors, particularly in those models of PBL, where project-organization is a corner-stone. Here, individual subject courses are intended to support and expected to be included in the projects. There is, however, evidence to suggest that the integration of course content in projects is proving difficult for some students.

During an aide to teaching staff in the process of re-organizing a semester on Medialogy at Aalborg University (AAU), researchers found that students struggle to identify the relevance of individual courses in relation to projects. The students also had difficulties with the sequencing of the subjects in courses, some stating that it seemed off compared to status in projects as well as with transferring course-content (L. B. Kofoed et al., 2019). Some courses however, seemed easier to integrate, and students attributed this to what, in essence, are Didaktik considerations, where the subject-matter is presented in a practical and relatable manner to projects (p. 1474). The authors note that the students' perceived disjunction between courses and projects cannot be isolated to a single semester, but could be habits formed over previous semesters (p. 1478). The integration of course content into projects are central to the AAU PBL model (Askehave et al., 2015), and the experienced disconnect points to an area in need of further research. In line with Kelly (2004), the authors suggest a holistic approach when developing a curriculum with the intended union of courses and projects (L. B. Kofoed et al., 2019). By revisiting qualitative interviews conducted by members of a cross-faculty research project called PBL Future, we will analyze the collected data at 4th semester Medialogy, by applying Basil Bernstein's concepts of classification and framing (B. B. Bernstein, 1996). For some, it may seem like a counter-intuitive choice, as Bernstein was a vocal critic of progressive education because of its invisible pedagogy. However, Bernstein was no theoretical purist and called such approaches 'epistemological botany' (Moore, 2013, p. 5).

Our aim with this paper is then to apply a set of conceptualizations presented by Bernstein. In the following, we will outline the previously conducted research and background, then outline the theoretical framework of classification and framing, and finally apply it to the qualitative interviews and curriculum data. We are, in other words, spectating with different interpretive frames than what the data has previously been subjected to (Charmaz, 2014).

2 Background

Before presenting the theoretical framework, we will outline how the data was collected and the original rationales surrounding the collection. We do this both to acknowledge the work conducted by our colleagues and to add transparency to our process. PBL Future is, as mentioned earlier, a cross-faculty research project addressing different aspects and potentials of the institutional and systemically practiced

PBL model at AAU (Kolmos et al., 2019). PBL Future consists of four distinct subprojects and a baseline study, researching topics such as self-directed learning, flipped semester, and post-digital collaboration, to name a few. This paper is a collaboration between members of the baseline study and the subproject researching a flipped and integrated semester structure.

The subproject that originally collected the data from students and teaching staff and initiated the flipped learning approach, was motivated to do so by empirical data from previous students on the semester, that stated that further integration of the courses into the project work would be an improvement (Kofoed et al., 2018; Kristensen et al., 2020). These difficulties with integration at AAU have previously been highlighted as a consequence of the 2011 decision to require all courses to have stand-alone exams, replacing the earlier system which allowed for courses to be examined through the project exam (Hüttel & Gnaur, 2017). Flipped learning methods was chosen to mitigate these problems as these have previously shown to provide students with an opportunity for increased interaction and a deeper involvement and engagement with course material (Johnson et al., 2015).

3 Data collection

The data used in this article is, because of the cross-faculty collaboration, a collection of both baseline data and data from the flipped and integrated semester. Data from the flipped and integrated semester is the base of the analysis. The flipped and integrated semester is a research project acting on the concerns of organizational and structural integration problems within the AAU PBL-model. In co-creation between teachers at 4th semester Medialogy (AAU CPH) and the research team, an experiment of applying a flipped classroom approach in all three courses at a semester and focusing on in-class activities that integrate course material and the semester project work has been running first time in the spring 2019 and is running again in spring 2020. For data collection an explorative case study approach (Remenyi, 2013) has been used. Research methods such as observations, student surveys and teacher interviews have been used give insights into different aspect of this new flipped and integrated semester. In this paper we will only analyze five semi structured interviews, one with each of the teachers at the 4th semester of Medialogy. The interviews were conducted in the spring of 2019 and is part of the first iteration of the new re-organized semester design. The interviews have an average length of 35 minutes and have been transcribed and coded (Kristensen et al., 2019). The thematic codes used for this analysis is explicit examples of classification and framing as they emerge during the interviews.

4 Theoretical Framework: Classification and framing

Educational knowledge is, according to Bernstein (2003) realized through three intertwined message systems; a curriculum that defines what counts as valid knowledge, a pedagogy that constitutes what is considered a valid mode of transmission of knowledge, and lastly, evaluation defining a valid realization of knowledge is (p.77). The rules and principles for the selection of content, pedagogy, and evaluation can be drawn together as an 'educational knowledge code.' Bernstein described two general types of curriculum based on the relation of contents, either as closed or open. In the former, the content is 'well-insulated,' meaning the boundary of the content is clear-cut. In the latter, there is, on the other hand, reduced insulation, where the boundary of content is blurred. Bernstein (2003), respectively, call these a collection type or an integrated type, both with different variations on this horizon. Each of these is transmitted by a pedagogical device affecting the potential pedagogical discourses (1996). This pedagogical discourse is an oscillating 'struggle' between an 'official recontextualization field' (ORF) governed by state and allied agents, and a 'pedagogic recontextualization field' (PRF) governed by teaching staff.

Collection types and integrated types is organized in distinct ways with different levels of rules, student autonomy, hierarchies, and establishments of subject loyalty. The collection type is a highly specialized curriculum with clear subject boundaries. The relation between teachers and students is hierarchically organized, with little room for student autonomy. Education is here a slow initiation into the mystery of the subject, where students learn more about less. In the integrated type, the emphasis is on education in breadth. For the integration to work, the supra content must focus more on general ideas than in the collection type. The integration also affects staff relations, who must establish consensus for the integration and blurring of content boundaries (B. Bernstein, 2003; B. B. Bernstein, 1996). This can be related to potential knowledge gaps in PBL, where breadth is sacrificed for depth (De Graaff & Kolmos, 2003), but where the exemplary dives ought to be 'a mirror of the whole' (Wagenschein, 2015). The insulation has apparent consequences for the organizational structure of the university. In a collection type, the hierarchy also presents in the relationship between staff and Principal and typically manifested as a traditional top-down power structure - as we also saw in the pedagogical relationship. In the integrated type, the power distribution is more complex and divided between networks establishing alternative power bases. Relating this to a Danish context, one could be critical of the notion of PBL universities (or any university) as an integrated type from a Bernsteinian perspective because of the structural changes following the University Law of 2003, where a more corporate approach to running the Danish universities was put in place (Wright & Ørberg, 2008). Consequently, increasingly opaque and hierarchically organized management was put in place instead of the complex constellations of collaborative networks proposed by Bernstein. This has been further bolstered by the process of standardization and outcome descriptors, moving from academic subject mastery to intended learning outcomes (Bologna Working Group on Qualifications Frameworks, 2005; Karseth, 2008).

4.1 Classification and Frame

To analyze the types of curriculum, Bernstein (1973) introduces the concepts of classification and frame (see figure 1).

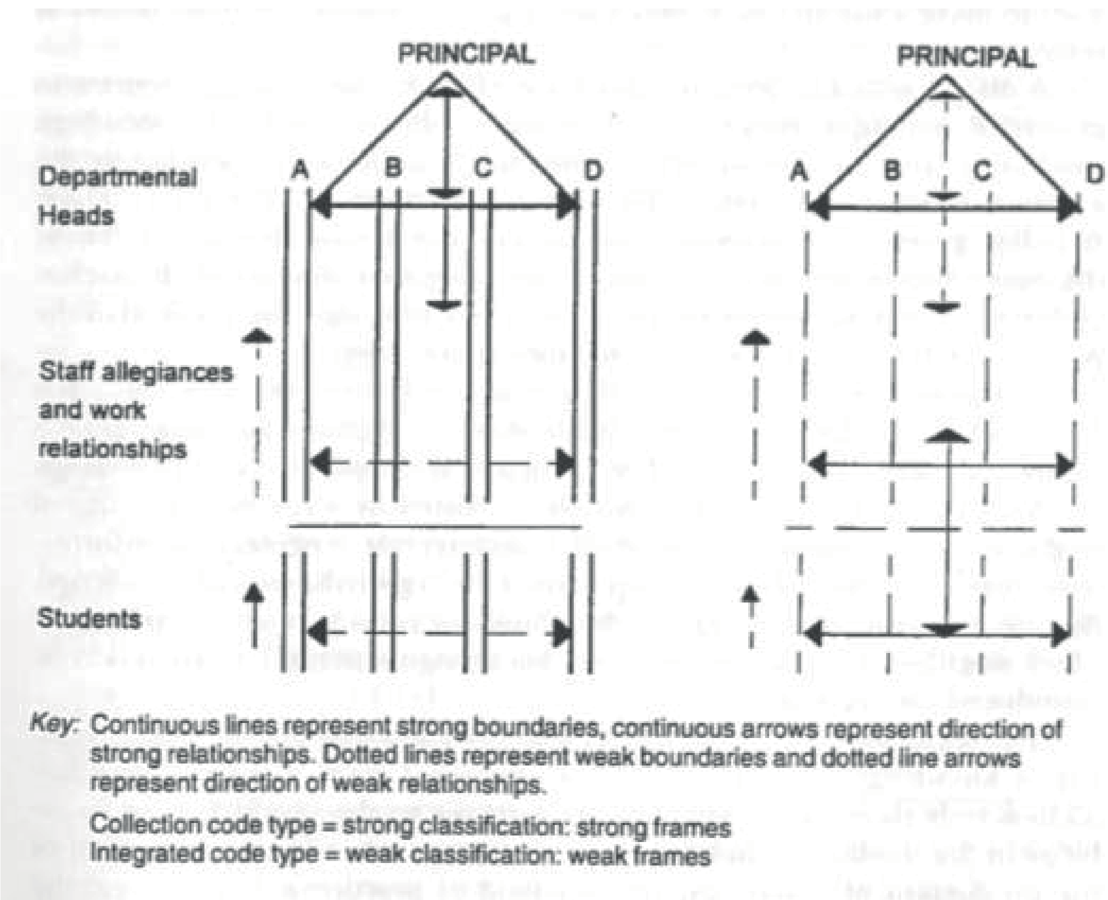

Figure 1 Strong and weak classification (B. B. Bernstein, 1996, p. 24).

Classification refers to relations between content or categories and the degree of insulation, and how these boundaries are maintained. A strong classification delineates clear boundaries, whereas a weak classification refers to blurred boundaries between categories. Insulation serves two functions, one external to the individual and one internal, by which disciplinary identity is created. Classification is then a question of power, and changes in the classification reveal these power relations. Any changes in the classification result in changes in what is perceived as a unique identity, be it gender or discourse, to name a few. Parting in a discussion of the trivium and quadrivium curriculum of old European universities (see for instance Doll, 2012; Muller, 2009 for discussions on the periodical transition of the liberal arts and practical knowledge in the trivium and quadrivium), Bernstein (1996) argues that discourses exist as both singulars and regions. For educational researchers, this notion provides a way of understanding educational subjects as singular discourses and an educational program as a region (1996, p. 23). A region is an appropriated space, previously empty, given a unique name. A collection of singular discourses set within a strong classification serves a regionalization of knowledge. This process requires recontextualization of discourses when determining which are suited for the new region, and is a place of ideology (1996, p. 23). As we shall later see, this aspect is particularly relevant when teachers evaluate the scope of projects in PBL, as some students may traverse to peripheries of accepted discourse and perhaps beyond.

Frame refers to the pedagogical relationships between teacher and taught. Classification address the limits of *what* discourse to include, framing address the potential pedagogical realization of the selected discourse (B. B. Bernstein, 1996). Framing is then about apparent control, of who controls what, be it 'selection, organization, pacing, criteria of communication and the position,' to name a few (B. B. Bernstein, 1990). Strong and weak frames respectively limit or enhance options for the teacher and taught when regulating the features that constitute the communicative context and the realization of potential pedagogical discourses (B. B. Bernstein, 1990, 1996). Analytically, framing serves as a regulator of two intertwined systems, but their rules can change independently of each other; rules of social order and discursive order. The rules of social order are constituted by what we previously presented as the pedagogical relation, excepted behavioral traits, or vocational ambitions. The rules of the discursive order are composed of the 'selection, sequence, pacing, and criteria of the knowledge.' Bernstein (1996) also refers to these rules as regulative discourse and instructional discourse (p. 28). When framing is strong, the pedagogy is visible, and in the opposite case, invisible to the student, or what Bernstein sarcastically denotes as a 'progressive' framing.

Nonetheless, the two rules form the pedagogical discourse, and as it moves from one 'site' to another, a transformation takes place. Bernstein (1996) reformulate the pedagogical discourse to a principle of recontextualization 'which selectively appropriates, relocates, refocuses and relates other discourses to constitute its own order' (1996, p. 47). The principle thus creates agents with recontextualization functions, moving the pedagogic discourse to recontextualization fields mentioned earlier, which plays a crucial role in the autonomy of education as a whole.

5 PBL Principles, Classification, and Framing

Relating the concepts of classification and framing requires us to delve briefly into the overarching principles of PBL (De Graaff & Kolmos, 2003; Guerra, 2017). The most evident is the centrality of the problem as the vehicle for learning. The learning processes are student-centered, social and experiential in nature, drawing on knowledge of the individual student and peers (Baden & Major, 2004). The student-centrism requires self-direction in the learning process, and, tying a knot to Bernstein (1990, 1996), an ability to find and establish a classification between courses and acceptable discourses. The students themselves in the less visible pedagogy of PBL, becomes agents in the field of recontextualizing and transforming a pedagogical discourse with their own, in essence creating a new region of discourses. The vital part on the supervisor is then to secure a sense of coherence between the disciplinary discourse accepted by practitioners, and the 'newer' region of assembled discourses created by students. If the discourse is outside the realms the accepted and established region, the students are venturing from the accepted classification that creates a unique identity in effect weakening the established classification (B. B. Bernstein, 1996).

6 Analysis

Both classification and framing are viable concepts when planning and analyzing a PBL curriculum. For this purpose, we will analyze a single semester undergoing significant changes on a university with systemic integration of PBL. First, we will analyze the classification as presented in the formal curriculum, and the courses that are intended to support the students' project work. Issues of pacing and sequencing from a student perspective has previously been described by Kofoed et al. (2019).

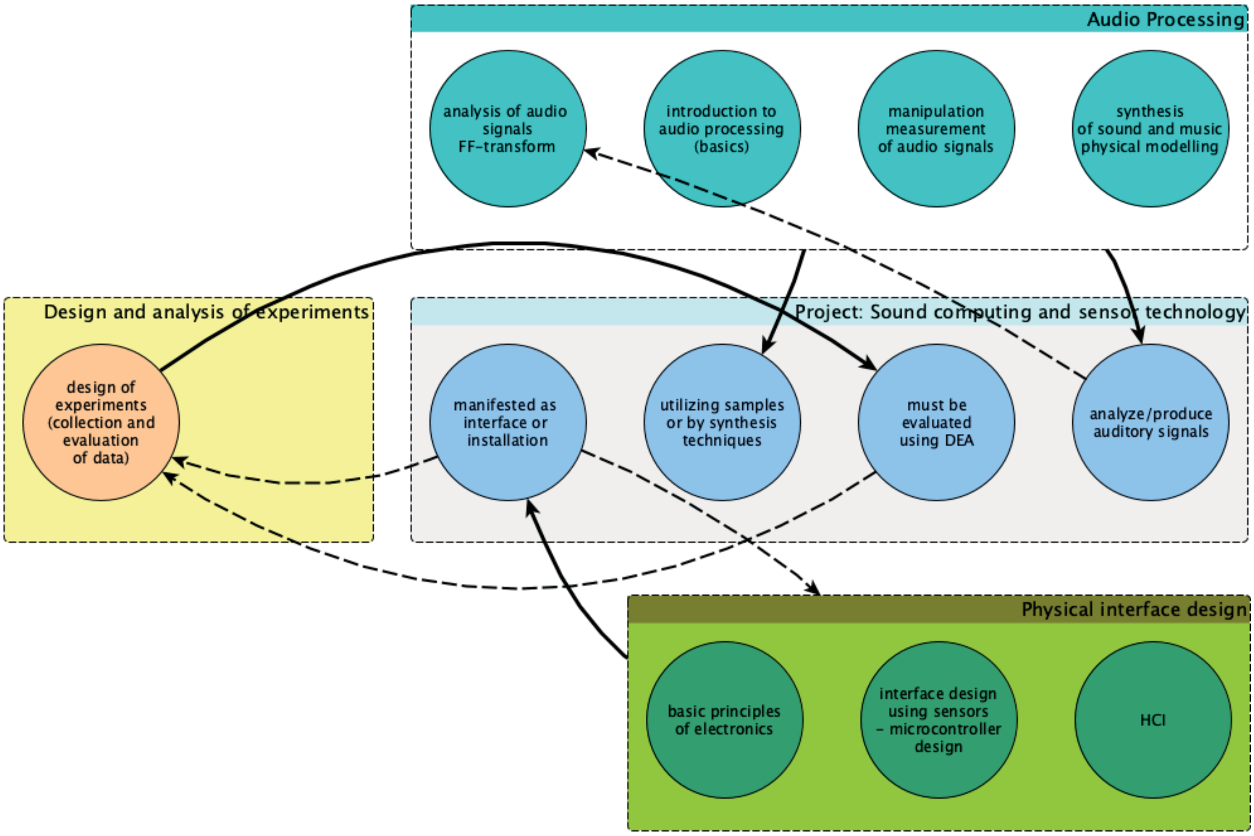

Figure 2 Classification between courses on 4. semester (based on educational goals from the formal curriculum for Mediology Aalborg University, Copenhagen 2017)

Figure 2 shows a graph of the relations between courses and project. At this particular semester, there are three courses, 'Audio processing' (AP), 'Design and analysis of experiments' (DEA), and 'Physical interface design' (PID). Courses are, according to the AAU PBL model, intended to support projects set within a semester theme (Kjersdam & Enemark, 1994), here 'Sound computing and sensor technology' (SCST). The courses and project are thematically summarized with distinct topcis in each circle. The topics are based on the broad intended outcomes stated in the formal curriculum. The dotted lines moving from SCST to the courses are the stated outcomes supported by courses, showing an outward relation from the outcomes of the project to the courses. The other edges delineate a relation between outcomes of courses and outcomes of the project. One example: In SCST, students' are expected to develop a manifestation or installation enabling users to utilize a physical interface to manipulate sound or synthesis in one way or another. This must be evaluated by planning and conducting an experiment. As each course supports these intended outcomes of the project, the boundaries between project and courses are, on paper at least, blurred. But as the graph (figure 2) shows, there is no apparent relation between courses. Although classification between projects and courses are weak and the relation reciprocal, the classification is in this graph stronger between courses. Despite the explicit statements and the at-glance weak classification, Kofoed et al. (2019) still find that students still struggle to integrate course content in projects, and, to paraphrase Bernstein, venture so far from the established discourse, that they almost create a new one.

7 Analysis of interviews

Looking at the classification within the enacted curriculum through the scope of interviews with teaching staff and going in to the case of 4th semester Medialogy we see that the teachers, despite the weak classification at the intended level of the curriculum, experience their respective courses as being isolated. They experience a strong classification between courses and semester projects in the enactment. Despite being a group of only five teachers working together on the 4th semester, the teachers are not usually coordinating or working much together:

> *"I don't remember talking to anyone about what is happening on the other courses, although it was the same people organizing the courses. We didn't talk, I didn't know what was happening. Now I have a much clearer idea of what is going on in the other courses."* (Teacher A: 19.39)

Teachers did not have a structured meeting culture and the responsibility of practical coordination concerning the semester falls upon the semester coordinator. Thereby, the classification in the enacted curriculum is much stronger than described in the intended. An attempt to mitigate this was made as a part of the new structure of the semester, by reorganizing the teaching staff into networks, an aspect also noted as vital by Bernstein (1996) for the integrated curriculum type.

Multiple initiatives have been made to support the weakening of the classification between courses and projects on the 4th semester. The research team coordinated meetings with the teacher team and put themes of integration on the agenda. Themes such as knowing each other's courses and discussing the students' work with the semester projects and more framework orientated planning of the semester was discussed.

Weakening the classification between courses and projects was also attempted by using exercises in the courses, as an interviewee explains:

> *"In PID we started every lecture with something like, use the sensors that you plan to use or that could be used in your semester project and do the exercises from there. […] The goal was established by us, using elements that they know they will use or hope they will use in their semester project."* (Teacher B, 18.30).

Working with framing as a part of weakening the classification was also done in different ways. A range of activities were planned to blur boundaries of course content and projects. One example is joint supervision of projects. Similarly, a joint workshop week was planned to reach the students at a certain point in the sequence of courses to facilitate the potential integration of the students' work thus weakening the perceived classification of courses.

> *"Another thing is that we aim for a particular framework and knowledge level between PID an AP. We aim for a particular time framework to gather all the information together so it can be connected – the week 15 workshop."* (Teacher A. 12.19).

The teachers tried to create a suitable framing for the students, where specific activities were intended to facilitate potential integration of subject matter into projects. Teacher A says:

> *"what helped was at the joint supervision day we got an idea about the different requirements so every time we had a topic in the lectures that might help the projects we highlighted them. That was a positive part"* (13.23).

The excerpt serves as an example of the intertwinement of classification and framing; certain points in the framing of the sequence of learning activities served to weaken the perceived strong classification between course contents and project. However, in a learning environment emphasizing high degree of student autonomy not all groups were in the same part of the anticipated sequence. The pace of the individual groups was not aligned, and at the joint workshop this became a problem.

8 Discussion

In this article, we have attempted to operationalize two concepts developed by Bernstein. Our ambition has been to elaborate on the potentials for analyzing various elements constituting an 'educational whole' in PBL. Rather than broad types and variations of PBL (Baden & Major, 2004) or modes of universities and curriculum orientations (Kolmos, 2017), we propose the conceptualizations presented are relevant across multiple variations of PBL, emphasizing a holistic approach when aiming for integration of subject content and teaching activities. This requires a collaborative effort and complex power distributions in networks, and as one interviewee responded, hitherto, this has not been the case. Noted by Bernstein (1996), this is a pivotal part of an integrated curriculum type. In some sense, then, the invisible pedagogy of progressive education criticized by Bernstein not only affect students but unintentionally leave teachers in the dark. Further, formulating explicit outcomes intended to aide the students in setting an acceptable trajectory fails to do so in a satisfactory manner (Kofoed et al., 2018). Consequently, a collaborative effort of integration set in a student-centered teaching environment cannot be reduced to teaching-staff or researchers alone. Instead of changes in responsibility of teaching and learning (Steiner-Khamsi, 2009), participatory and collaboratory networks of students, teachers, and researchers co-create suitable classification and framing

In a PBL environment like the one analyzed in this article, much of the learning is dependent upon the project and the students' engagement in it, which is why it is so essential to ensure as much alignment between the intended integration of courses and project and the enacted. This has been the biggest motivation for trying to operationalize Bernstein's theory and apply it, and we feel that there is a great potential for doing these types of analysis, gaining valuable insights across many different intertwined elements that impact intended, enacted and experienced learning. There are many other theoretical elements from Bernstein that we feel could be applied to great benefit of the research community, analyzing the discourses of different courses, the pedagogical device etc.. We also feel that this type of analysis should be expanded to cover not only the intended and enacted levels of the curriculum as we have done here, but also how it is experienced by the students.

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Collaboration, Reflection and Imagination: re-thinking Assessment in PBL education for sustainability

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Abstract

Higher Education Institutions are increasingly aware of the urgency of the global sustainability crisis and making efforts to prepare a new generation of students to rise to the challenge. New sustainability initiatives are appearing in numerous disciplines, from introducing sustainability contents to disciplinary courses, to overhauling entire curricula with an interdisciplinary, problem-based approach to environmental issues. However, little attention has been paid to the role of assessment in education for sustainability – creating a problem where students want to engage in rethinking the world of tomorrow, but feel constrained by outdated individual, disciplinary, recall-based examinations that do not promote effective engagement. We noticed this at Erasmus University College (EUC), a liberal arts institution in The Netherlands that uses the seven-step (a.k.a. "Maastricht") approach to problem-based learning. Our previous research showed EUC students experienced despair about sustainability issues but did not feel empowered to act on it. In response, inspired by alternative sustainability scholars Donna Haraway, Anna Tsing, Cyril Dion, Pablo Servigne, Renée Lertzman and Stephen Sterling, we developed three new forms of assessment for a bachelor PBL course called "The Climate Crisis". Our aim was to foster three key attitudes identified by these thinkers to help us through the sustainability crisis: collaboration, (self) reflection, and imagination. In this PBL practice paper, we present the modes of assessment that we developed: firstly, a collaborative documentary filming project about climate change in the Netherlands; secondly, a reflection diary which the students use as data to write a meta-reflection essay on their journey in coming to grips with climate change; finally, a world-building essay in which students use their imagination to contemplate the rest of their lives in a warming world. We conclude on a brief assessment the impact of these new assessment methods on students through an analysis of the end-of-course evaluations.

Keywords: Sustainability Education, Problem-based learning, Assessment.

Type of contribution: PBL practice paper

1 Introduction

16 of the warmest years on record have occurred in the last 17 years, and on current greenhouse gas emission reduction pledges, the Earth is on track to warm up by 3 degrees Celsius by the end of the 21st century (IPCC, 2018). Such warming would have a catastrophic impact on human civilisation, and possibly trigger a series of cascading "tipping points" that push the Earth System towards a "hothouse" state in which human and animal life may not be able to endure (Steffen et. al., 2018). In the face of such a threat, teaching sustainability at the university level is no longer a "nice-to-have" option but a fundamental requirement if universities are to stay relevant in the coming decades. The necessity of adapting higher education curricula to tackle the existential threat of climate change is hardly disputed anymore, but the discussion now centres on the means by which this "wicked problem" (Rittel & Webber, 1973; Head, 2008) should be taught. Indeed, our designation of climate crisis as a wicked problem alerts us to the way in which the climate crisis combines elements of uncertainty - we do not yet know what global warming is going to mean for us - value divergence - there are large gaps in public awareness of and appreciation for the issue of global warming - and complexity - it is a multiplicity of problems that poses disciplinary conundrums and societal challenges (see Head, 2008). In this capacity, it also challenges dominant models of education.

For decades, Education for Sustainable Development (ESD) scholars have been advocating a paradigm shift in learning approaches at all levels of education, from transmissive to transformative, instructive to constructive, and imposed to participative (Sterling, 2001). Such a shift requires a pedagogical approach that is process-oriented, open to critical (including epistemological) inquiry, collaborative, reflective and in which teachers act as both reflective practitioners and agents of change. These proposed changes align almost exactly with the tenets of the Critical Pedagogy movement (Freire, 1968; Biesta, 1998), which suggests that we might learn from critical pedagogy in developing the appropriate pedagogical approaches for the ecological crisis. In particular, critical pedagogy advocates the use of *problem-posing* education, a form of group-based critical inquiry centred around real-world, meaningful problems. The overlap between critical and ecological pedagogy makes sense in that critical pedagogy concerns itself with education as a vehicle to social justice, which strongly overlaps with environmental justice.

Concretely, critical pedagogy has mostly been implemented in higher education in the form of project-based, problem oriented forms of learning (Andersen & Kjeldsen, 2015). There is nothing inherently critical or transformative about either project-based or problem-based education. Indeed, within fields like engineering education or medical education, both project work and problem-based learning have been implemented merely as methods to improve student learning outcomes and competences, with no critical objectives in mind. However, both approaches are amenable to being co-opted within a critical education for sustainability programme. In this paper, we will focus on a case of critical problem-based learning for sustainability, which comprises both short problem scenarios *and* a student project.

More particularly, the case will focus on the assessment practices developed for the interdisciplinary bachelor-level PBL course "The Climate Crisis". Assessment has always been a contentious subject in both critical pedagogy and ESD (Keesing-Styles, 2003; Reynolds & Trehan, 2000). Indeed, standardized exams are often seen as anathema to the ethos of critical thought and action. On the other hand, providing no assessment at all is both impractical in a university system in which grades are a requirement, and unhelpful to students for whom assessment is still very much a guide for learning, even in a PBL environment (Norman, Neville, Blake & Mueller, 2010). But between standardized exams and assessment-free learning, we hope to build a case (literally) for constructive and creative forms of assessment that do not seek to punish and reward, but to empower students.

2 Situating the case

Erasmus University College is a Liberal Arts and Sciences bachelor-level teaching institution based in Rotterdam, the Netherlands, in which the predominant form of teaching is the seven-step model of problem-based learning (Moust, Bouhuijs & Schmidt, 2007). The college offers a broad, interdisciplinary bachelor, which proposes disciplinary and interdisciplinary majors and minors divided amongst four departments: Life Sciences, Humanities, Economics & Business and Social & Behavioural Sciences. In response to the demand for education for sustainability, EUC has created an interdisciplinary sustainability major for students with sustainability-oriented PBL courses offered by several departments. The case studied in this paper is the interdisciplinary course *The Climate Crisis*, coordinated by the authors of this paper and integrated within the sustainability major. *The Climate Crisis* is an eight-week course, comprising both PBL tutorials and lectures.

The course is structured as follows:

Table 1: Structure of The Climate Crisis course.

Week	Subject	Disciplines	Assessment
1	Welcome to the Anthropocene: the state of the climate and future projections	Climate Science; STS studies	/
2	Beyond the Anthropocene: conventional historical narratives on climate change and their challengers (Capitalocene, Plantationocene, Chthulucene).	History; Philosophy	/
3	Climate inaction: the role of states and the fossil fuel industry in slowing climate action	Political science; political economy	/
4	Future scenarios of climate change: social capitalism, post-capitalist transitions and collapse.	Political economy	Group Project Deadline
5	Climate Change as a problem for the mind: from the individual to the collective	Psychology; Philosophy; Post-colonial studies	/
6	Reconceptualising and reimagining the future in a warming world	Philosophy, post-colonial studies	Short Essay Deadline
7	Narratives for the future: poetry and prose for the climate crisis	Literature studies; Arts & Culture	/
8	Writing week	/	Final Essay Deadline

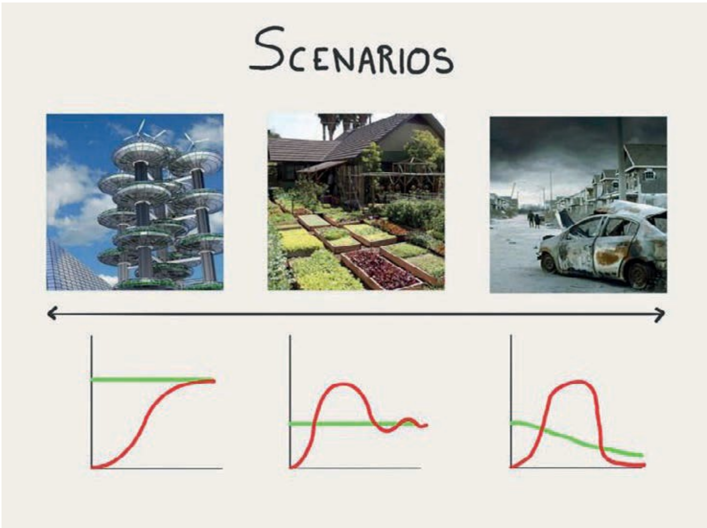
In this course, we expect the students to attain the following:

- Have an overview of the scientific consensus on anthropogenic globalwarming.
- Become aware of the current impact of the climate crisis on the world, and be able to apply this in Dutch context.
- Be familiar with possible trajectories for global warming in the future, and the consequences of these trajectories for the biosphere and human civilization (economics, politic, society, and culture).

- Have an understanding of the different ways in which the climate crisis has been conceptualized and historicized, and have an awareness of the relative strengths and weaknesses of various conceptualizations.
- Understand the political, social and economic mechanisms that have prevented and continue to prevent timely action on the climate crisis.
- Be familiar with possible scenarios for a transition to a post fossil-fuel global system, in particular the Green New Deal economic transition scenario, the Post-Capitalist economic, political and social transition scenario, and the systemic collapse scenario(Collapsology).
- Develop an awareness of the psychological processes at play in the human mental apprehension of the climate crisis at the individual and collective level, and a self-analysis capacity in terms of these psychological processes.
- Develop the sensitivities and creativity necessary to re-imagine life under the climate crisis.

Although the seven-step PBL method is not inherently critical, it is adaptable to a critical pedagogical approach that focuses on student transformation rather than merely information transmission. Thus, each problem for the course was written with a view to challenge students to question their world-view, promote critical discussion, and help students to make the connection between the theoretical knowledge they acquire through the readings and lectures of the course and the practical actions they can take in the fight against climate change. The learning goals for this course were truly “open” in that the tutors did not try to steer students towards pre-determined goals listed in a tutor manual, as is often the case in PBL.

To give the reader an idea of how PBL was implemented in this course, below is one of the PBL problems from the course. With no prior reading or any other information, the students had about one hour to discuss this problem scenario in their group of 12 and formulate learning goals for the following week’s reporting phase. A student chaired the meeting, and the tutor guided the discussion and provides critical questions and insights for the students to discuss. While there were suggested readings and videos provided for each week, students could also look for their own materials to answer their learninggoals.



Scenario 1: Social Capitalism; Scenario 2: Post-capitalism and controlled de-growth; Scenario 3: Collapse

Figure 1: PBL Problem Week 4 from the Climate Crisis: Future Scenarios in a Warming World

In designing this course, we were informed by different disciplinary problematizations of climate crisis: as a scientific, economic, political, and psychological issue, but also as an issue for the humanities. Following scholars working in what has come to be known as the “environmental humanities”, we also took the climate crisis as a problem for thought and the *imagination*. In so doing we followed Morton (2014), who understands climate change as a “hyper-object”. He suggests that dominant epistemologies for understanding climate change treat it as an “external” object. This, he argues, limits us in apprehending the ways we are bound up with various part-human, part-nonhuman ecologies. We also drew on Stengers (2015) and Latour (1993; 2017), who convincingly argue that certain “modern” habits of thought - e.g. habits of thought that distinguish between “nature” and “culture”, between science and politics - are inadequate in the face of the climate crisis. We also drew inspiration from Haraway, whose recent work *Staying with the Trouble* (2016), emphasizes the necessity of situated theorizing and story-telling in attempts to reconsider human life under conditions of climate catastrophe.

The climate crisis, furthermore, disrupts dominant political-economic understandings of reality. As Jameson (2003) provocatively suggested: “it is easier to imagine the end of the world than the end of capitalism”. Drawing on Parenti and Moore (2015), and Klein (2014), for instance, we emphasized the connection between ecological histories and histories of capitalist expansion and extraction. We thereby offered students modes of narrating history that go against the grain of a dominant “capitalist realism” (Fischer, 2009), in which “there is no alternative” to current modes of production. The course also called for a consideration of the ways in which colonial histories and contemporary, structural forms of racism shape environmental injustices (Pulido, 2018). Our course asked students to not simply look for “solutions” in the shape of more sustainable production (although that would surely help), but also for a reconsideration of what it means to be human. The course was shaped by understanding the climate crisis as an event that calls for alternative modes of imagining and being human.

Yet, with all the best intentions, the course could only achieve its objectives if the assessment was constructively aligned with the learning outcomes (Blumberg, 2009). Providing no assessment at all has been tried, tested and found wanting in a PBL context (Servant-Miklos, 2019), and it remains a truism that assessment steers the learning (Norman, Neville, Blake & Mueller, 2010). We realised early on that enforcing a standardized exam, even with open questions, would be epistemologically incompatible with our critical pedagogy approach, as it would encourage students to look for “correct answers” in the readings rather than thinking through and discussing the material critically. Looking at the intended learning outcomes, we chose instead to develop new forms of assessment focused on critical skills for ESD, critical pedagogy, and the environmental humanities: collaboration, reflection and imagination. In this paper, we will explain the rationale behind these forms of assessment, provide a description and roadmap for implementation of the assessment format, and critically evaluate the outcomes in terms of the learning objectives. We chose to focus on assessment specifically in this paper because it is an underdiscussed topic in the field of PBL and sustainability education.

3 Assessing the Climate Crisis: Collaboration, Reflection, Imagination

A diverse group of scholars point to the climate crisis as an event that challenges dominant habits of philosophical and political thought (Haraway, 2016; Parenti & Moore 2015; Morton, 2013; Latour, 2017, Stengers 2015), in particular modern epistemologies that place human observers in an exterior position to nature, and political-economic ideologies that treat capitalism as the only possible mode of production and by extension, mode of life. Given these insights, it becomes imperative to not only mobilize students’ critical capacities, but also their imaginative resources. Is it possible to think and imagine humans’ relationships in and with their ecologies in terms less defined by extractivist and neoliberal logics? How might it become possible to live relatively well under conditions of ecological collapse? Can we, instead of finding safety in technocratic geoengineering or appeals to “green capitalism”, stay with the troubling realization that current, Western modes of life have to be reinvented? The imagination is a crucial resource within this educational project.

3.1 Collaboration: Group Project on Climate Change in the Netherlands

You will be asked during the first PBL session to form groups of 4 (with possibly one or two groups of 3, depending on class size). With your group, you will write, record, edit and produce a short podcast on Climate Change in the Netherlands. How you organize your group is up to you and you will receive one collective mark at the end. You should pick your area of interest - for instance, you could focus on farming, ice-skating (e.g. the elfstedentocht that has not happened since 1996!), conservation, sinking buildings, preparing for sea-level rises, or whatever you think is interesting.

The idea for this assignment came from the focus group research with the students that showed a very poor understanding of the impact of climate crisis on their home country. Indeed, many students believed that the climate crisis would mainly affect developing countries and were blind to the impact that rising temperatures are already having right where they are. To tackle this problem, we harkened Sterling's (2001) call for a move towards collaborative, participative and bottom-up sustainable education. This has been echoed by Wals (2007), who coined the term "social learning" as a response to the sustainability crisis, with an emphasis on dissonance, diversity and social cohesion towards the co-creation of alternative futures (Peters & Wals, 2016). In addition, addressing social issues through collaborative critical engagement in and out of the classroom is a staple feature of critical pedagogy and social-transformative education (Servant-Miklos & Noordegraaf-Eelens, 2019). We therefore designed an assignment that would combine group work within diverse, international groups of students, and engagement in the climate crisis with the local community. EUC is a very international college, and therefore requiring students to work in group immediately added an extra dimension of cross-cultural collaboration. This challenge brought with it interesting questions of group dynamics, particularly between students of different ethnic backgrounds, given the discussions of racial injustices present in the course – we will say more on that in the evaluation section. Focusing the podcast on the Netherlands both addressed the students' blindness to climate change as a problem for the here and now, and enabled them to leave the ivory tower of the college and build bonds within the communities, as for example the students who went to interview farmers during the recent farmer strikes in The Hague, the students who talked to parents to find out how climate change plays on the decisions they make with regards to child-bearing and rearing, or the students who went to the port of Rotterdam to find out how the flood defences are holding out.

Assessment criteria for the group project:

- Scientific basis of the podcast (i.e. are the facts correct, from scientific sources, up to date etc.). The reference list is also assessed as part of this criterion.
- Quality and relevance of the podcast contents and story-telling (i.e. what does the podcast tell us about climate change in the Netherlands? Does it tell a coherent and compelling story?)
- Quality and relevance of the interviewees and interviews. The list of interviewees is assessed as part of this criterion.
- Aesthetic quality (i.e. the podcast audio quality, the quality of the sound editing, the podcast makes innovative use of sound to convey mood and message)
- Clarity of the transcript (i.e. no grammar, spelling or syntax errors, the transcript is accurate)

3.2 Reflection: Using Psychological Theory to Critically Reflect on Student Attitudes

The Climate crisis raises questions about our abilities to respond to it – in other words, our response-ability. This is difficult at the level of the state or the market – the macro level – but also at the individual level. For this assignment, you will draw on the psychological literature presented in week 5 to make sense of and reflect on your own responses to the climate crisis. You are limited to 1000 words, excluding references. You may choose to draw on your climate crisis diary as a source of inspiration for your essay, though you will be asked to be analytic and academic in your writing - you are not being assessed on your response to the crisis, but on your ability to apply psychological theory.

We devised this assignment in direct response to previous course evaluations in the sustainability major and focus groups on sustainability education at the college that hinted that students felt overwhelmed and lost among the daunting facts and challenging narratives they learned about in sustainability education. For this course, we therefore devised a self-reflection piece that would provide students with pathways to thinking and feeling their way through the brutal epistemological and ontological shifts required by the course. Firstly, to help the students, we designed a personal digital diary for them, inspired by the kinds of diaries used in qualitative diary studies (Mackrill, 2007) - i.e. with guiding questions to help them structure their thoughts and feelings. For each entry, the student is asked: is this entry as a result of a triggering event or a general reflection? If it's an event, what's the event? How do you feel? How are you reacting to that? Any general thoughts or reflections?

Students were not required to fill in the diary, though we offered a guideline of "minimum one entry a week". This diary was neither read not assessed by the course coordinators. However, they were invited to use the diary as primary source material to help them write a short academic essay conceptualising their thoughts and feelings about the climate crisis. To assist in this conceptualisation, students were invited to familiarize themselves with key areas of research in climate psychology. They were introduced to eco-anxiety (Pikhala, 2018), in which the climate crisis causes the weakening of ontological security; cognitive dissonance and other cognitive biases that hamper our ability to act in the face of the climate crisis (Johnson & Levin, 2009); the concept of climate grief and mourning (Cunsolo & Landman, 2017); environmental melancholia and the myth of climate apathy (Lertzman, 2015). Finally, they were challenged to reframe their own thoughts and feelings about the climate crisis using concepts from identity theory such as the reflexivity *v.* habitus debate (Adams, 2006), moral identity (Strohminger & Nichols, 2014), and environmental identity (Clayton, 2003). We opted for an academic essay rather than a free-form peace to encourage students to think critically about themselves and take some distance from their own thoughts and feelings. We expected that this would help to reduce the students' feelings of being overwhelmed. Because we do not want to judge the students' feelings and thoughts, the grading criteria for this essay focus on academicrigour:

- Quality of the chosen structure (i.e. are the themes relevant, analytic rather than descriptive)
- Quality of the analysis (i.e. did the student make good use of theoretical concepts, do the concepts fit, and if they used quotes, didthey use appropriate quotes to justify the choice of concepts?).
- Ability to conceptualise the self (i.e. was the student able to distance themself and look at themselves critically and academically?)
- Quality of the academic writing (i.e. is it written as an academic essay, did they use proper grammar, syntax and spelling, is the essay properly referenced?)

3.3 Imagination: World-Building Essay as a Pathway to Possible Futures

During the course, you will have encountered the notion of SF and World-Building in Donna Haraway's work. You will also have attended a workshop lecture by Frank Keizer in which you explore the imagination, poetry and aesthetics in the age of the climate crisis. For this assignment, you may use the following forms: Academic paper; Speculative Essay; Visual Essay.

Imagine it is the year 2100, you are still alive, in your twilight years. Tell the story of your life through the great transformation of the Climate Crisis. You may also try to take the perspective of another person or being: you may be or have been a US migration lawyer, or a Ghanese Bauxite miner, an Australian firefighter – even a nonhuman being, like a very old sea turtle, an old oak or baobab tree. Of course, you will have to do your research in order to tell 'their' stories in a plausible, if speculative way.

You can think of the following things, though you don't need to cover all of them in detail: energy (i.e. did we switch from fossil fuels, and if so, how?); food (i.e. did some food disappear, are we growing food differently etc.); shelter (i.e. did parts of the world flood, are parts of the world uninhabitable, did we have to rethink *housing etc.); economy (i.e. what happened to the global free trade capitalist system?); politics (i.e. what happened to liberal democracy, what happened to the national state, what happened to supranational institutions?); society (i.e. how did people react to the climate crisis? What happened to the refugee question? Did people help each other out or turn on each other?)*

In calling upon students to imagine life 'in the ruins' of climate change (Tsing, 2015), we aimed to challenge students on four counts. Firstly, we asked them to come up with a convincing story about how climate change would affect them or an imagined other on earth, including the possibility that this other may be a plant or animal. This assessment *explicitly challenged* the human-centred mode of history-writing that is dominant in the Anthropocene discourse. Secondly however, we also highlighted the necessity to *think ecologically*. That is: relationally, and in an interdisciplinary fashion. In our writing prompts, we asked students to connect matters of economics, energy supply (and possible transitions), agriculture, politics, and culture. This also means that while they had to use their imagination, they had to think carefully and deliberately, taking into account up-to-date climate science as well as the real constraints posed by dominant political and economic institutions. Thirdly, in so-doing, we emphasized story-telling as a *situated practice*: we asked not a general account of "life on earth", but a specific one, situated in a specific constellation of factors that shape people's experiences of climate change. The students have been equipped for this task throughout the course, in which they have learned about the matters of race and class in relation to the historical roots of the climate crisis and contemporary forms of environmental injustice. Last, we emphasized the different possibilities of *genre:* while they were free to write a more academic essay, they could also experiment with form itself, incorporating the visual register and other aesthetic elements. In case the students elected to work visually, the material has to be supplemented with a narrative and references detailing the way the visual product is substantiated by, and brought in relation to, the course literature.

Assessment criteria for the world-building essay:

- Comprehensiveness of the world-building (i.e. does the account provide a multidimensional aspect?)
- Scientific basis of the world-building (i.e. is it scientifically credible?), including quality of the references cited.
- Systemic thinking (i.e. did it take into account the requirements for and effects of solutions or changes that the student imagined?)
- Aesthetic quality of the world-building (i.e. aesthetic quality of the writing either prose or poetry, quality of illustrations, if appropriate).
- Story telling (i.e. did the student write a coherent, compelling narrative rather than just a string of facts and ideas?)
- Grammar, syntax and spelling, referencing.

4 Case outcomes: Results and Evaluations

The official course evaluations run by the university gave us some good insights into the general appreciation for the course, which was quite high among students. However, these official evaluations do not contain specific information about the assessment. Therefore, we sent out a short questionnaire to our 93 students, of which 24 responded (the response rate was likely hampered by the disruptions surrounding the covid-19 pandemic which closed the university two days after the course ended). The questionnaire contained 3 questions (listed in table 2) which students could answer using a seven-point Likert Scale where 1 means "not at all" and 7 means "very much". In addition, students could leave a freeform comment about each of the assessment formats.

Table 2: outcomes of a 7-point Likert scale post-course survey (n = 24), where 1 = not at all, and 7 = very much.

Question	Mean	Mode	SD
Group Project: Climate Change in the Netherlands - To what extent did this assignment improve your collaboration skills?	4,75	4	1,29
Short Essay Assignment: Applying Climate Psychology Theory to Individual Climate Responses - To what extent did this assignment improve your reflection skills?	5,42	6	1,18
Final Essay Assignment: SF and Worldbuilding - To what extent did this assignment improve your creative and imagination skills?	4,88	7	2,05

For the first assignment, the majority of students found that the assignment did indeed help them learn to work together, as exemplified by this comment:

> *I really liked the format of a podcast plus researching about something that is actually happening within our immediate environment was very interesting. In the beginning, it was challenging to incorporate all group members equally, but closer to the deadline it forced us to work closely together. On hind sight, I really appreciate this project and the amount of group operation it forced us to do.*

However, a minority of students felt that the assignment was frustrating for non-Dutch students as they felt they could not participate equally in the project. One student also made a very interesting point, that "collaboration" in the narrow sense of students working together is perhaps not the best descriptor for the skills acquired here. We should find a term that encompasses outreach into society as well for next year:

> *I don't think that the biggest take away from this assignment is the improvement of collaboration skills as I have done many group projects. I believe that the biggest take away was that we were engaging with what climate change means locally and having conversation with people that or whose profession are already affected by it really highlighted that climate change is an immediate and not an abstract crisis that we are facing.*

For the second assignment, an overwhelming majority of student felt that they did indeed improve their reflection skills, even if it did not come easily:

> *First I thought this assignment was stupid and that you just wanted us to "have a breakdown" to become more climate aware. But in writing the assignment, I actually realized a lot about myself and about my attitudes towards myself and towards the climate crisis. I think this was a very good assignment.*

For a few students, however, there were concerns that psychology is too individualistic a discipline to help tackle the climate crisis, and that forcing students to reflect using psychological concepts might channel their thoughts into pre-established categories. This is a fair point, and we need to think about addressing this for next year, perhaps by emphasising more collective and fluid approaches:

> *To a large extent, I appreciated that the assignment departed from the simple "replication of knowledge" format and encouraged reflection. Nonetheless, as I noted when doing the assignment, I am not sure that individualizing responses is necessarily the best way to go, especially for a group of people who might already be quite self-reflective already. I felt climate psychology may have more of a disabling than empowering effect.*

Opinions were more divided on the final assignment. For a lot of students, this way of working was completely new, and many felt overwhelmed by being asked to write something like this. Some felt that this was not an appropriate assignment for an academic institution, that such creative work should beleft to art schools.

Quite a few felt constrained by the requirement to “stay with the trouble” (Haraway, 2016) and not escape into science fiction.

> *This was a really fun assignment to write. However, because we also had to include more technical details and everything had to be coherent, it was sometimes hard to find a balance between creativity/writing freely, and backing this up with (academic) sources. I understand that the essay and the world you write about needs to be realistic, but it was hard to find that balance.*

However, the mode for this question was 7, meaning that the largest group of students thought this assignment very much helped develop their imagination skills:

> *Definitely! it improved my imagination skills. I wanted to do an academic paper at first but forced myself in some ways to write an sf* [science fabulation – a concept from Haraway, 2016] *narrative. I think it is uncommon in university to have this type of essay. It really helped me broaden my imagination and force me to see beyond. Really frustrating assignment at first because it was out of my comfort zone but at the end of the day I can only see the benefits and the fun it brought me*

5 Conclusion

In this paper, we proposed a novel approach to assessment in a PBL course on *The Climate Crisis*. The approach to the course was steeped in critical pedagogy, ESD and the environmental humanities, resulting in an interdisciplinary, problem-based, student-centred course in which traditional examinations had no place. In designing the assessment, we therefore focused on critical skills required for “co-creating alternative futures” (Peter & Wals, 2016), namely collaboration, reflection and imagination. Through this paper, we hope to have provided a rich background for the choices we made in designing the assessment, and sufficient clarity on the nature of the course and the requirements and grading criteria for the assignments. Our aim is that other ESD educators who wish to make use of PBL in their classrooms might take inspiration from the assessment approaches that we have designed.

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Implementation of New Methods and Programs (BIM)

Cross disciplinary Project Based Learning in the context of Building Information Modelling

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Abstract

The successful planning of construction projects requires a cross disciplinary cooperation of planners with different expertise. Building Information Modelling (BIM) as a modern networked working method offers the chance to improve digital planning workflows as well as communication and collaboration during a project. This paper raises the question of how Building Information Modelling (BIM) can be taught to students and presents an example of best practice in the field of Project Based Learning (PBL).

The promotion of BIM competencies requires a flexible teaching scenario that addresses all levels of the learning taxonomy enabling dynamic, self-organised and networked teaching-learning-scenarios. The below described cross disciplinary PBL-scenarios offer an adequate approach to address the above challenges.

In this paper, the authors describe the development of a joint PBL-based teaching-learning project between HTWK Leipzig and TU Dresden. A practical example scenario was created, in which students from various disciplines were divided into different specialist groups depending on their field of study. Therefore, different roles were distributed in the respective groups, whereby various responsibilities were assigned according to the individual learning backgrounds of the students. Overall, students from different institutions worked together in a common planning process specifically developed for this project. With the help of digital collaboration tools the physical distance between the two institutions was overcome. Thus, the concept matches real-world-planning scenarios since usually representatives from specialised disciplines are based in different locations.

The evaluation of the students did not only focus on the final results, but above all on the cooperation between the individual groups. Special attention was paid to the professional communication and data exchange between disciplines. Throughout the course, students had to analyse and design their own approach to the teaching and learning scenario, supported by regular consultations with teachers considering feedback and reflecting new experiences of the participating students.

Keywords: Project Based Learning (PBL), Building Information Modelling (BIM), digital collaboration, cross disciplinary learning, best practice

Type of contribution: PBL best practice

1 Building Information Modelling as a challenge for institutions of higher education

This section introduces Building Information Modelling (BIM) as a construction methodology, illustrates the requirements for teaching BIM and explains the role and importance of Project Based Learning (PBL) for teaching BIM.

1.1 Introduction to Building Information Modelling

In accordance with German, European and international legislation, various planners with different fields of expertise are involved in a building construction project (ISO 19650-1, 2018; BS PAS 1192-3, 2014). An essential requirement for the successful completion of planning activities is the coordination between the different stakeholders throughout the project. However, numerous real-world projects suffer from time delays or ballooning budgets and thus illustrate the need for a new approach to the planning process (Keller *et al.*, 2006; Hausknecht & Liebich, 2016). In response to these challenges, the German government issued a phased plan for the implementation of the new planning method BIM in 2015 (Borrmann *et al.*, 2015; BMVI, 2015).

The methodology of BIM contains the following essential components:

- the object-oriented modelling approach of digital models (ISO 16739-1, 2018);
- a standardised vocabulary specification (ISO 12006-3, 2007; ISO 6707-3, 2017);
- the transparent, model-based communication and collaboration between the responsible roles (BS PAS 1192-2, 2013; ISO 29481-2, 2012; ISO 19650-2, 2018), and
- the consistent management and verification of data models throughout the life cycle of a building (BMVI, 2015; Hausknecht & Liebich, 2016).

Due to the outstanding importance of BIM and the fact that students will become the acting engineers of the future, students must have in-depth knowledge and intensive work experience of the BIM method. Therefore, this paper discusses the requirements for how to successfully teach BIM in institutions of higher education. In a second part, the authors present an approach on how to embed PBL-features into BIM education.

1.2 Requirements for teaching Building Information Modelling

Based on John Biggs' method of Constructive Alignment, the design of a teaching concept begins with the question of the learning outcome to be achieved. This means in this case: what is the essential knowledge, and what are required practical skills in BIM that graduates of an institution of higher education must be capable to demonstrate after having attended an advanced BIM-course based on a PBL-teaching and learning scenario (Biggs & Tang, 2011)?

The BIM method includes a wide range of competencies that must be taught to students in order to enable them to successfully practice BIM, such as: (i) the technical ability to create models, (ii) the professional competence to manage data, (iii) the critical awareness to validate models, and (iv) the ability to communicate with partners from other disciplines. Therefore, the first challenge of teaching BIM is to combine and foster the diversity of BIM skills in a single teaching-and-learning concept.

Currently, the knowledge of successful BIM deployment continues to develop dynamically. For this reason, BIM teaching concepts must be highly flexible and adaptable to new achievements, especially in the development of technical standards, software systems and process management.

An essential part of the BIM method is the cooperation of planners from different institutions and disciplines. This aspect requires students to work together with peer students from other faculties and other fields of study. As in real-world scenarios, students from different faculties have different learning backgrounds and different expertise. That is why it is essential to formulate targeted learning objectives in cross-institutional, cross-faculty PBL-scenarios.

1.3 Project Based Learning for teaching Building Information Modelling

Since BIM is a complex way of working considering technical, professional and human relationships, numerous academics developed advanced teaching-and-learning scenarios (Fruchter, 1998; Menzel *et al.*, 2004). It became clear that project-based, interdisciplinary teaching-and-learning approaches are required to bring together students from different domains (Menzel *et al.*, 2006), or in simple terms: BIM cannot be taught just by describing a theory.

Such a teaching approach can be realised by focussing on selected BIM use cases. Use cases are partial processes of the overall process which contribute to the achievement of the defined BIM objectives by using BIM models (BMVI, 2019). In the presented project, the selected use cases are aligned with the competencies of the students involved. When selecting an adequate BIM use case, it is important to ensure that students work on all essential components of BIM allowing them to fully explore the relationships between these components. Finally, it is essential for students to bring prior knowledge from their distinct areas of expertise enabling them to fully focus on learning BIM methods (Guerra *et al.*, 2017).

PBL is well known as an approach for teaching and learning, in which students gain both - knowledge and practical skills - by investigating an engaging, complex problem with real-world challenges over a prolonged time period. Thus, PBL is an adequate approach for students to study the state-of-the-art of BIM. In addition, PBL gives students who come from different disciplines an opportunity to share their respective expertise and experience. By working together on a common problem, students can reflect on their individual perspectives and are encouraged to harmonise them. The elaboration of strategies to coordinate requirements of different participants is an essential challenge in the professional practice of planners and engineers which can be trained in particular by PBL methods (Du *et al.*, 2009).

2 An inter-institutional Project Based Learning-Scenario for Building Information Modelling

This chapter introduces the PBL-BIM course scenario developed by the authors. The main condition for the cooperation between HTWK Leipzig (Leipzig University of Applied Sciences) and TU Dresden (Dresden University of Technology) was set by the funding body of the project, the SMWK (Sächsisches Ministerium für Wissenschaft und Kunst, engl.: Ministry of Higher-Education and Fine Arts). This condition required the collaboration of two distinct institutes of higher education, e.g. a university and an institute of technology. Another requirement was for the maximum possible utilisation of teaching and learning tools developed, implemented and maintained by 'Bildungsportal Sachsen GmbH' (BPS), an e-learning initiative founded and sponsored by the local government of the state of Saxony. The PBL-scenario presented below is funded by BPS from May 2019 to December 2020 (BPS, 2019).

2.1 About the Participants

Participants for the below described PBL-BIM-scenario were enrolled in different degree programmes. At HTWK Leipzig students were enrolled in an elective module (6 ECTS) offered to students of two Master Degree Programmes, such as 'Civil Engineering' and 'Building, Energy and Environmental Engineering' in their third semester. It should be noted that students of civil engineering came from different specializations.

At TU Dresden the PBL-scenario is part of an elective module (8 ECTS) offered to students in the third year of the 'Diplomingenieur' degree programme (a five-year degree comparable to a '3+2' integrated Master degree). Again, students are enrolled in different specializations, such as 'Structural Engineering', 'Construction Engineering', 'Construction Management', 'Energy Systems', 'Transportation Engineering' and 'Hydraulic Engineering'. A total of 50 students participated in the PBL-BIM-scenario in the winter term 2019/2020, 32 coming from HTWK Leipzig and 18 from TU Dresden.

2.2 The Project Based Learning-Design Scenario

Since PBL focuses on the investigation of a complex, real-world problem, students from both institutions were exposed to one joint design task, following two distinct collaboration approaches.

The students were provided with a shared site specification hosting a complex of two buildings connected by a steel-frame structure (see Figure 1). Each student cohort (Leipzig and Dresden) was responsible for one distinct part of the building, i.e. the left part of the building was planned in Leipzig and the right part planned in Dresden. The design task was developed by research assistants and academic staff with the aim that both didactic and practical concerns appeared balanced.

Figure 1: Completed building as a result of the module (HTWK Leipzig: left part, TU Dresden: right part)

2.3 Task Allocation

The focus of the BIM-PBL project differed between the two institutions. At HTWK Leipzig, the emphasis of the project was on the usage of BIM as design-support and integration tool. Thus, students were grouped into specialist teams, while the emphasis at TU Dresden was on the modelling processes in BIM. Therefore, the tasks for the students were allocated by floors. A larger emphasis was on integration management. Table 1 summarises the task allocation.

Table 1: Groups of students

Institution	Team name	Field of study	Size of group
HTWK Leipzig	Object Planning	Civil Engineering	5 students
	Structural Engineering	Civil Engineering	7 students
	Technical Building Services	Energy, Building & Environm. Eng.	7 students
	Building Physics	Civil Engineering	5 students
	Construction Management	Civil Engineering	8 students
TU Dresden	Ground floor (Object Planning, Technical Building Services)	Civil Engineering	7 students
	First floor (Object Planning, Technical Building Services)	Civil Engineering	5 students
	Second floor (Object Planning, Technical Building Services)	Civil Engineering	6 students

The different approaches in Leipzig and Dresden were created due to the different teaching foci of the participating institutes (HTWK Leipzig: 'Institute of Civil Engineering, Building Construction and Building Physics'; TU Dresden: 'Institute of Construction Informatics'). The differences in the focus of the two institutions have the benefit that both types of commissioning in construction projects are represented. The task allocation in Leipzig corresponds to the individual commissioning of specialist planners, whereas in Dresden it corresponds to the commissioning as general planner.

3 Overall didactic concept – modification of the Seven Jump model

In the context of PBL, amongst others, the Seven Jump model of Maastricht University has been established (see Figure 2 and Moust *et al.*, 2005). It structures the learning process into 7 steps from clarifying terms to the synthesis of the learning outcomes containing a mixture of group work and independent work (Slemeyer, 2013). The concept of the BIM course presented in this paper extends the Seven Jump model to 'problem-based project work' (Dombrowski & Marx, 2018).

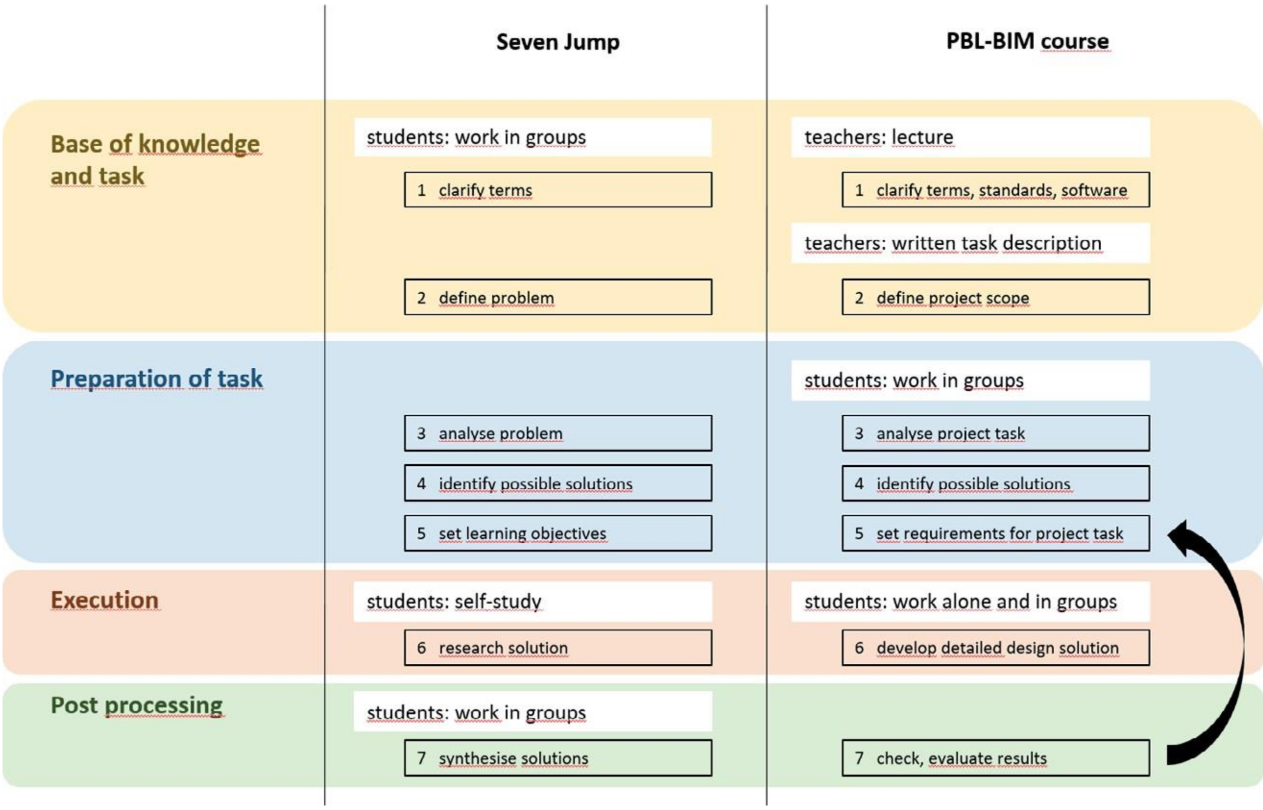

Figure 2: Structure of Seven Jump from Maastricht University and modification for the PBL-BIM course

First of all, in the case of the presented PBL-BIM-project, the starting point is a well-defined project task. In comparison, PBL usually focuses on a problem that comes up by a trigger, e.g. an anomaly or contradiction (Du *et al.*, 2009). In this project, these aspects are part of quality management in the later phases.

Secondly, the Seven Jump concept is based on the idea that students independently acquire the basic knowledge by means of the trigger and thereon define the problem to be investigated (Du *et al.*, 2009). In this case, initial support was provided to students, with a special emphasis on managing the BIM-processes. Since a large number of students had to work together in a collaborative manner, it was decided that teachers should provide the initial specification and framework to be worked on.

Thirdly, the Seven Jump model assumes that the development of solutions for the defined learning objectives by the students can take place in an independent phase (Moust *et al.*, 2005). In comparison, the work in a BIM project contains a collaborative part by definition and therefore it cannot be done independent of peer students.

Figure 2 provides an overview of the extensions of the Seven-Jump-Model made by the authors to better address the requirements of this PBL-BIM-project. Furthermore, the authors of this paper have assigned a superordinate structure to the steps, consisting of four levels, including: Level 1: ‘Base of knowledge and task’, Level 2: ‘Preparation of task’, Level 3: ‘Execution’ and Level 4: ‘Post processing’.

4 The four-level concept demonstrated

In this chapter, the individual steps of the modified Seven Jump model are explained in more detail with reference to the implementation in the PBL-BIM course jointly delivered by HTWK Leipzig and TU Dresden.

4.1 Level 1: Base of knowledge and task

Since BIM is a complex, interdisciplinary product and process modelling activity, it covers a substantial body of knowledge. Therefore, it seemed to be desirable that students are provided with some guidance how to acquire knowledge in the different areas, usually through lectures but also through workshops and seminars. Furthermore, to address the dynamically changing BIM-body of knowledge, additional talks by senior engineers and other practitioners were offered to all students over the whole term. In their talks, these company representatives focused on one specific area of BIM and described their approaches and experiences. With the help of these talks, students had an opportunity to frequently compare their own doing against practical relevance. Moreover, students got suggestions for alternative solutions.

Step 1: Clarification of terms, standards and software to be used

Due to the collaborative nature of the presented PBL-BIM-course lectures, workshops and seminars were live-streamed and recorded. Access to the knowledge base was provided through the jointly used teaching and learning platform (OPAL). Thus, a one-stop-shop to access all teaching and learning tools and material was available to the student cohort. The availability of recorded material created more flexibility for learning independent from location and time. More specialist knowledge was available to students, since a total of eight academics (seven from HTWK Leipzig, one from TU Dresden) contributed to the creation of the knowledge repository.

Jointly organised workshops focused primarily on the introduction of students to commonly used tools, such as BIMcollab (a digital task management platform offering the use of BIM data) and Solibri Model Checker (software application for digital checking of BIM models). These workshops also contributed to the team building process, since they were organised as face-to-face meetings.

Step 2: Definition of project scope

Generic task specifications were prepared by the lecturers and handed out to the students at the beginning of the term, including major constraints and milestone specifications. These included:

- planning specifications for the object to be modelled by the students structured into subject-specific tasks;
- the grouping of students in teams with the allocation of corresponding roles (see chapter 2), and
- proposals for available domain-specific software applications (e.g. through university licences).

In addition, the necessary platforms for the overarching tasks of communication, data, version and quality management were provided (e.g. OPAL, BIMcollab, Solibri Model Checker).

4.2 Level 2: Preparation of task

Step 3: Analysis of project tasks

The project structure illustrated in Figure 3 provides a framework for the students, but at the same time offers freedom for the interpretation and exercise of roles and tasks. A multitude of open questions in the project task definition leads to the self-organised, creative and independent process of PBL.

After choosing their team, students developed an initial common understanding of the (domain-specific) tasks. The allocation of roles in the teams was managed differently. TU Dresden used the roles defined in BS PAS 1192-2, namely: Task Team Manager (TM), Interface Manager (IF), Information Manager (IM) and BIM Authors (BA). HTWK Leipzig used German guidelines, i.e. coordination activities were executed by one team member, called the BIM-coordinator (CO). Figure 3 provides a complete overview of the roles allocated and their interdependencies. In the PBL-BIM-project, a major result of this step is the BIM Execution Plan (BEP). The creation of such a document is also common in planning practice (BS PAS 1192-2, 2013; ISO 19650-2, 2018; Hausknecht & Liebich, 2016). The BEP-document provides a schedule of files, documents, tools, responsibilities and authorities for steps 6 and 7.

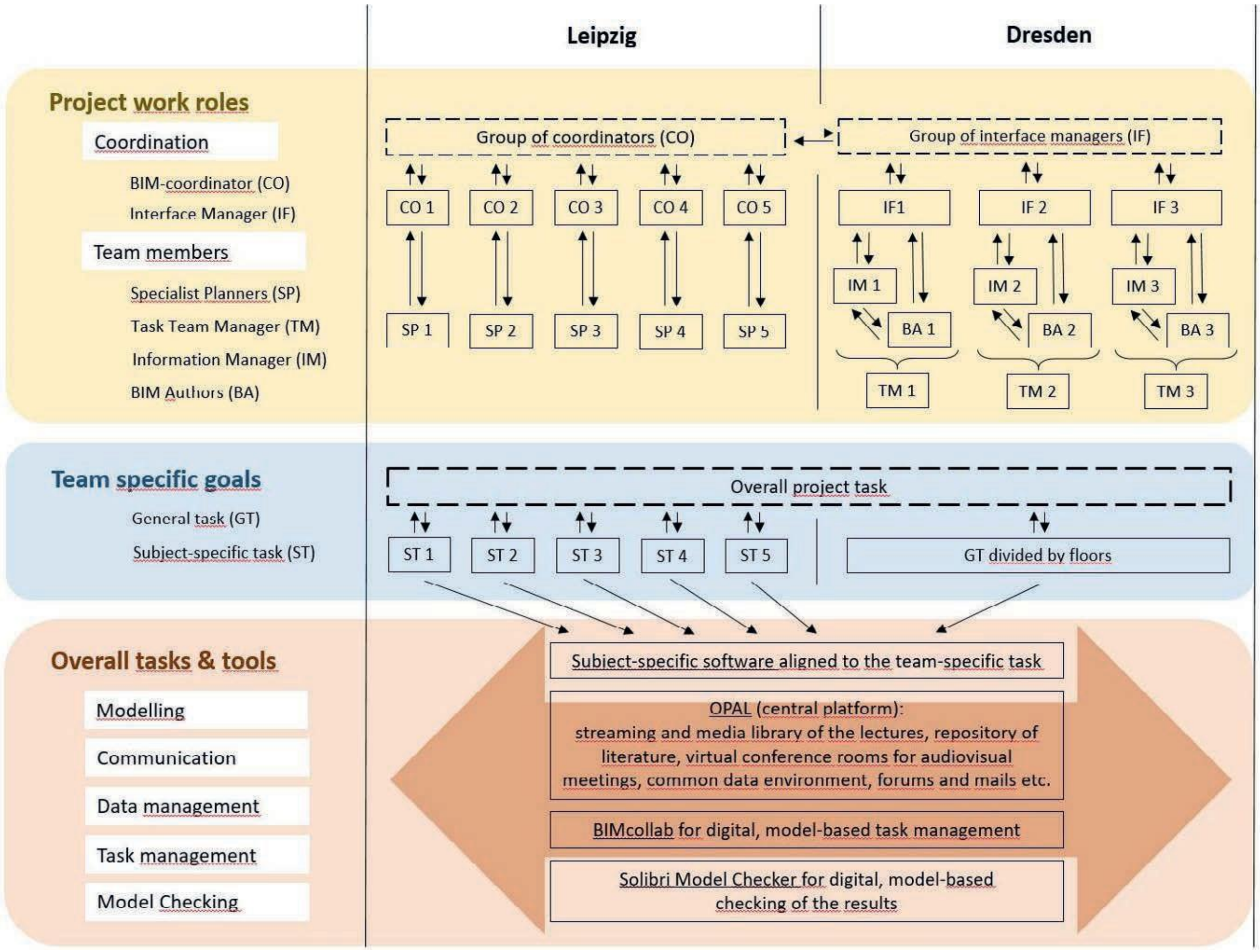

Figure 3: Overview of the project structure

Secondly, the students started to work on the detailed design based on the initially provided 2D drawings (sketches) with limited detail. Numerous engineering decisions had to be made by the students themselves. For this purpose, the students acquired additional domain-specific knowledge and skills how to manage various software applications. Thus, each student worked on a unique set of tasks. It should be noted that students depended on communication and knowledge exchange with peer students in order to complete their individual tasks. For example, the technical building services team needed the room model from the object planners and design details from the building physics team in order to calculate the design load of the heating system.

Step 4: Identification of solution approaches

In this step, students identified initial solution approaches to professional, technical and coordination challenges. Examples of professional challenges are the selection of a load-bearing system, or the creation of a supply concept for building services systems. Furthermore, students had to test technical solutions, e.g. for data sharing and modelling. Last but not least, workflows had to be defined and tested, especially with regard to the merging of subject-specific models into one holistic coordination model or the connection to the task management platform (BIMcollab). The results had to be checked from a professional perspective or to be evaluated from an IT management perspective (e.g. proposed data sharing concept).

Step 5: Set requirements for project task

BIM-coordinators from Leipzig and Task Team Managers and Information Managers from Dresden came together to coordinate and if required to harmonise the proposed solutions. The usage of virtual meeting rooms (e.g. AdobeConnect), as well as forums in OPAL, was recommended. Other tools could be used as well, but limitations and obstacles with respect to data security had to be taken into consideration by the students. Essential parts of the communication were to be documented by the students (e.g. by using log books).

As a result of step 5, students had to agree on the following: (i) a definition of settings in the software tools, e.g. settings for the export of IFC files (standardized, manufacturer-neutral files for the exchange of BIM models), and (ii) modelling requirements for the digital building models to be created, e.g. with regard to the geometry and information contained. Therefore, the BEP-document was supposed to be updated.

4.3 Level 3: Execution

Step 6: Develop a detailed design solution

The emphasis of this step is on the creation of digital building models aiming to document the outcomes of the collaborative design process. The set-up of a robust model-based communication is a prerequisite for the fulfilment of this task. This step is a core element of the PBL-BIM scenario. Thus, free working time of approximately 3 hours per week was set aside in the timetable. It was expected that students use this time slot for coordination and consultation activities with peer students and academic mentors.

4.4 Level 4: Post processing

Step 7: Check and evaluate results

Since the final goal of the project is to create a technically correct, functioning and conflict-free BIM-compliant building design, students were encouraged to frequently check their own achievements. Digital tools such as the Solibri Model Checker were provided, giving students an opportunity to create additional evaluation rules themselves. In the case that students would struggle to achieve the design objectives, they had to adjust their strategy and document this adjustment in the BEP-document, i.e. steps 5 to 7 form an iterative loop as shown in Figure 2.

5 Assessment methodologies used

A broad spectrum of assessment methods was used in the presented course, stretching from self-evaluation, through peer-evaluation, log books, report writing, to presentations. As one can see, the evaluation is not only based on the final result, but also takes intermediate achievements into account, reflecting and monitoring the learning process of students.

Self-evaluation became possible through the availability of the BEP-document and design briefs. Students and teams could always verify their own achievements against the collectively set targets and developed specifications. The availability of model checking software and the BIMcollab environment were the main enablers for peer-evaluation. Dedicated roles (CO, TM, IF) had the authority and responsibility to guide the whole student cohort through the peer-evaluation process. Log books enabled academic staff to perform an evidence-based evaluation of the communication and collaboration efforts of students. Moreover, the central component for the evaluation of the design skills was the submission of a final report, complemented by the digitally developed building model.

Finally, students had to present and defend their intermediate and final achievements in two presentations (intermediate and final presentation). The mid-term presentation enabled academic staff to holistically evaluate how students could already master the three BIM competencies (modelling, collaboration, data management) in an integrated way. Obstacles and deficits in the learning process could be easily identified and addressed in the second project period. In the final presentations, students were given the opportunity to demonstrate their final achievements. Furthermore, time was set aside for students to present feedback in order to enable academics to improve the PBL-BIM teaching concept in subsequent years.

6 Feedback from teachers and students

In the beginning of the PBL-BIM project students reported that the various degrees of freedom offered in PBL-scenarios were new to them, as they had previously participated mainly in direct instruction. However, students learned to master these challenges quickly. Some students argued, that additional time should be made available to the course in the overall curriculum, extending the PBL-BIM course to a two semester module. This would allow for a more detailed introduction to the PBL method, an improved team building process and more in-depth work on project tasks. Some preference was given to the management system with only one BIM-coordinator role per team instead of several management roles. Furthermore, one responsible, project-wide leading student role was recommended (e.g. project team manager to coordinate all BIM-coordinator and interface manager roles).

The overall feedback from students was extremely positive and motivating. Students stated that they felt they could acquire new knowledge and valuable skills and competencies for their future professional career. In particular, the ability to personally take over the responsibility for creating models, communicating as well as managing data and tasks increased students' confidence and practical experience. The methodologies underpinning BIM could be easier understood.

The feedback of the teachers involved emphasizes the fact that the presented concept of PBL enables students to reach a higher level of learning taxonomy. Beyond remembering, understanding and applying knowledge, the self-organised work on the project enables students to analyse and evaluate their work. Students are enabled to develop correlations between different aspects of BIM. With the BIM method particularly, it is important to deal with the planning tasks as concretely as possible, since many challenges only become apparent when planning processes are carried out. The authors of this paper can conclude that the focus on self-directed learning and the interpretation of the teacher's role as a facilitator contributes to a 'shift from teaching to learning' (Barr & Tagg, 1995). The findings of the authors correspond to findings of other colleagues reported earlier in the literature (Anderson *et al.*, 2001; Du *et al.*, 2009).

7 Reflections

This section reflects on the developed PBL approach by discussing students' development of competencies, presenting possible further enhancements of the course and describing the requirements for a validation of the developed approach.

7.1 Development of competencies

Basically students' development and their perceptions about the project were similar in both institutions. Differences arose in particular with regard to the emphasis of individual development: students from HTWK Leipzig acquired more subject-specific knowledge in the role of specialist planner, whereas students from TU Dresden gained more interdisciplinary knowledge dedicated to the roles of general planner or BIM-coordinator, respectively.

7.2 Enhancements

There are several options with regard to a further improvement of the presented approach. For example, the groups could be reduced in size so that several design alternatives can be developed simultaneously. This would encourage discussion about different design alternatives developed by students. However, the authors argue, in such a scenario the workload of the teams may increase, because especially the tasks of coordination, data exchange and model checking will become even more time-consuming due to the necessary version management.

Another possible enhancement is to further mix the team structure so that students from Leipzig and Dresden work together in one team. Such set-up would encourage the cross-institutional interaction of students. However, from a management perspective numerous changes would be required, such as the harmonisation of curricula, timetables, grading schemes, etc. Furthermore, module requirements and enrolment should be interconnected and harmonised, team-specific software and cloud applications at the universities are supposed to be synchronised, and subject-specific support should be expanded.

7.3 Validation of the implemented BIM process

Since BIM is a comparatively modern method that is in a development process, institutions of higher education have to regularly evaluate their teaching concept against new research trends and requirements from practice. For this purpose, the authors conclude that a close interlocking of research and teaching is of particular importance. In the presented project, the developed workflows of the BIM course are discussed with several partners from practice. Cooperations with regional planning offices in the research project 'DigiTransSachs' hosted by HTWK Leipzig (Radisch, 2018) and in the research project 'BIM4EEB' hosted by TU Dresden (Schröpfer, 2020) are examples for such important partnerships.

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Assessment methods in split-level (PBL)² for Building Information Modelling

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Abstract

This paper presents the results of a split-level (PBL)²-scenario implemented at University College Cork, Ireland. Participants came from a four year Honours Bachelor Degree Programme in Civil Engineering and a 90 credit, one year MEngSc. Degree Programme in Information Technology in Architecture, Engineering and Construction. The aim of the split-level (PBL)²-scenario was to improve the education in Building Information Modelling, with a special emphasis on networked working methods. The challenge for BIM-courses is always to expose students to all facets of BIM, i.e. Product Modelling, Process Modelling, Communication amongst interdisciplinary teams, version management and quality control.

Recently, the legislator in the U.K. came up with seven new distinct role models for BIM-projects, whereas three of these role models are expected to work on project level and four roles are expected to work on task team level. Different qualifications are required to deliver the activities in excellent quality and to execute the authorities of these roles on an informed basis in a responsible manner.

Educators, especially third level institutions, have limited opportunities to expose students to real world scenarios, covering all aspects of a BIM-project. The authors argue, that through the presented split-level arrangement the educational needs in BIM can be covered to the broadest extend possible with a much higher impact than reported in other teaching and learning scenarios.

The authors also present a holistic set of integrated learning outcomes, reflecting the above challenges. Finally, each presented learning outcome is underpinned with multiple performance indicators, allowing academic staff to implement a detailed, fair evaluation of students' achievements in PBL-scenarios in a holistic and integrated approach.

Keywords: assessment, problem-based learning, building information modelling, digital collaboration

Type of contribution: PBL best practice

1 Introduction

Numerous papers have been published in the area of Problem and Project Based Learning (e.g. (Fruchter, 1999); (Dunlap, 2005)). Authors argue that both PBL can be used to develop problem solving capabilities and self-directed learning. Project Based Learning contributes to further professional skills development, such as communication skills or teamwork (Passow, 2012); (Lattuca, et al., 2006). However, traditional engineering courses are content-oriented and aim to deliver 'specialised', discipline-specific knowledge (Marincovich 2000). Some authors call this teaching and learning style a 'silo-approach' (Warnock 2015) and list negative effects, such as low student motivation or insuf-ficient opportunities for students to solve 'wicked problems'. Only in a limited number of these papers the authors analysed the positive effect of PBL on the development of professional skills (Alves, et al., 2015). Warnock et al. (2015) state that "*It has been estimated that in a four-year engineering degree programme, a student will work on more than 2000 problems. In doing so, students are preconditioned to think that every problem has a correct answer.*" Consequently, different approaches to teaching and learning are required, aiming to stimulate critical thinking and the capability and willingness of students to deal with incompletely described (complex) problems which may have more than just one possible solution.

1.1 Drastic Changes in How the AEC-industry Works

Building Information Modelling (BIM) is a holistic approach on how to create, exchange, manage, and archive digital building documentation on a life-cycle oriented, cross-disciplinary way. The mandatory introduction of BIM for public projects in the UK in January 2016 has created new challenges for potential educators and employers of civil engineering graduates not just in the United Kingdom. Therefore, future engineers must understand (1) the design processes, (2) the available IT-support tools, (3) the manufacturing and construction processes and (4) the operational processes of buildings. Complementing skills for the successful management of BIM are (i) excellent communication skills, (ii) the capability to work in interdisciplinary teams, (iii) the capability to demonstrate leadership in a team, and (iv) the capability to manage the collaboration between multiple teams.

The design of a teaching-learning scenario which addresses the majority of the above listed aspects is a challenge. The authors argue that the $(PBL)^2$-split-level approach presented in this paper provides a suitable framework to address most of these educational goals. Therefore, this paper we investigate how $(PBL)^2$ could contribute to the development of professional skills, such as problem solving, leadership, communication, team-dynamics, and time management.

1.2 Problem Statement

Before the curriculum was changed to the $(PBL)^2$-approach, the "BIM-project" was not achieving much apart from using a commercially available design tool. In order to increase benefits to students and broaden learning outcomes (see Table 9) the project was changed to simulate an authentic industry case. Table 1 below presents more detail of these changes and the rationale behind it.

Table 1: Comparison of the project before and after change of curriculum

	Work & Communicate in Teams	*Practice Leadership & Cross-Team Collabor.*	*Manage Collaboration & Use Appropriate IT-tools*	*Understand Design Process*
Before	Very limited. Lecturer is project lead.	Review from lecturer at end of each phase.	Very little. Only within each team.	"In silo" design
After	<u>Two teams Three roles:</u> UG Team as Designers. PG Team as Project Lead. Lecturer as Client`s Rep.	Constant feedback from PG students. One UG-student acts as TTM.	Weekly collaboration meetings. CDE as data exchange & management platform.	Bigger exposure to industry processes. BIM Level 2 as per BS 1192(2) standard.

2 Pedagogical Methods

The teaching and learning approach presented in this paper is called (PBL)², since the authors use a combination of both; a project-centred approach to provide a multi-disciplinary design task stretching over four phases (one term). In each phase, students are exposed to a dedicated "wicked problem" to be solved using a Problem-Based teaching scenario. The teaching and learning scenario is called "split-level" since student cohorts from an undergraduate and a postgraduate Civil Engineering programme participated in the project described.

Since Project Based Learning and Problem Based Learning use the same acronym – PBL – we briefly discuss the commonalties and differences of both approaches. Both PBL are 'student-centric' teaching and learning methodologies in which the instructor's role focuses on facilitating students' learning instead of 'dispensing' knowledge to students. Instructors relinquish the control of the learning process by providing a greater autonomy to students enabling them to (self-)organise their learning process, i.e. students are encouraged to take over more responsibility for their own learning. Further commonalities are: Both approaches (i) focus on open ended problems, (ii) provide authentic applications of content and skills, and (iii) emphasize on student independence and "inquiry" (Litzinger, et al., 2011). Differences between Project and Problem Based Learning are summarized in Table 2.

Table 2: Differences between Project-Based and Problem-BasedLearning

Project-Based Learning	usually multi-disciplinary	"lengthy"	follows general steps	involves real-world, authentic tasks
Problem-Based Learning	usually single subject	"shorter"	follows specifically prescribed steps	uses case studies as wicked problems

3 Context for the Implementation of the Pedagogical Methods

A project-based design problem was initially specified for the undergraduate degree programme in the academic year 2014/15 based on material provided by the university's office of buildings and estates. Students completed a building information modelling (BIM) project for a three-storey, 'green' building (see Figure 1) in four phases, namely (1) project set-up, (2) core and shell design, (3) modelling of rooms and spaces, and (4) modelling of (selected) building services systems (see Table 3). The usage of authentic BIM-process definitions and related roles was introduced in the subsequent academic year 2015/16. In each of the four project phases students had to solve a phase-specific "wicked problem" with a special emphasis on quality management, i.e. the problem-based aspect was added in 2015/16. The total duration of the project was 12 weeks.

Table 3: Project phases and model content generated by students

		Phase 1 *Project Set-Up*	*Phase 2* *Core & Shell*	*Phase 3* *Rooms & Spaces*	*Phase 4* *Underfloor Heating*
UG-Team	*One Team per floor*	BIM Design Space	BIM Model Content	Derived Model Content	Embedded Model Content
	One BIM author per section	Grids, Levels Families	Walls, Columns, Slabs, Windows	Rooms and Spaces	UFH pipes
	Horizontal coordination	Define Borders	Connect Building Elements	Connect Spaces	Connect Pipes Adjust Flow Direction
PG-Team	*One Team per floor*	CDE: Common Data Environment	Federated Systems	Federated Systems	Model Server
	Vertical coordination	e.g. Workspaces, Acc. Rights, Names	e.g. Linked Files (LF)	e.g. LF w. advan-ced interfaces	e.g. Work Sets

3.1 Participants

A total of 47 (2015/16) or 40 students (2016/17) participated in the design project described. The UG-course was part of the 2nd-year in a 4-year BE-programme. A further characterization of UG-students is provided in Table 4. The postgraduate course (5th year) was part of a 90 credits, 1 year MEngSc-programme. In the students' breakdown we also show the professional background of PG-students, i.e. the area in which the Bachelor degree was awarded (Table 5). The vast majority of PG-students had industry experience.

Table 4: Breakdown of UG-student cohorts

	Total	*Irish*	*Non-Irish*	*Male*	*Female*
UG (2015/16)	32 (100%)	27 (85%)	5 (15%)	23 (72%)	9 (28%)
UG (2016/17)	36 (100%)	35 (97%)	1 (97%)	32 (89%)	4 (11%)

Table 5: Breakdown of PG-student cohort

	Total	*Irish*	*Non-Irish*	*Male*	*Female*	*Architecture*	*CompSc.*	*Engineering*
PG (2015/16)	15 (100%)	9 (54%)	6 (46%)	13 (87%)	2 (13%)	2 (15%)	2 (15%)	11 (70%)
PG (2016/17)	4 (100%)	4 (100%)	--	4 (100%)	--	---	1 (25%)	3 (75%)

3.2 Roles and Responsibilities

Two team-roles were defined for the project, Project Teams and Task Teams. Project Teams were supposed to act as Design Lead or Main Contractor. These teams comprised of PG-students. A Project Team had to fill three distinct roles, including the Project Lead Designer, the Project Delivery Manager, and the Project Information Manager.

Table 6. Rotation of roles in PG-teams.

PHASE 1 and 2			*PHASE 3*			*PHASE 4*		
pLD	*pDM*	*pIM*	*pLD*	*pDM*	*pIM*	*pLD*	*pDM*	*pIM*
Student 1	Student 2	Student 3	Student 3	Student 1	Student 2	Student 2	Student 3	Student 1
		Student 4	Student 4					Student 4

Role descriptions were defined in compliance with British Standard BS 1192-2 (2013).

Project Lead Designer (pLD): This role manages information development and approvals. It confirms design deliverables and has the overall lead for configuration management. It is responsible (1) to enforce spatial coordination, (2) to confirm the status and approve information for issuing within the common data environment (CDE), and (3) to approve design changes proposed to resolve clashes.

Project Delivery Manager (pDM): This role assures the delivery of information exchanges. It confirms suppliers' ability to deliver against information requirements. It is responsible to accept or reject information exchanges within the CDE.

Project Information Manager (pIM): This role enables a reliable information exchange through a CDE. It maintains and receives information into the Information Model and enables the integration of information into the Building Information Model. It configures information for project outputs and populates the information exchange format for the Information Model. Responsibilities for this role are: (1) to enforce the project BIM standard and ensure delivery of the information requirement, (2) to accept or reject information exchanges within the CDE. This role has no design responsibility or right to issue instructions.

Task Teams were supposed to act as Specialist Designer or Subcontractor and comprised of eight UG-students. A Task Team had to fill four distinct roles, such as task BIM-Originator (n=4), task Information Manager (n=2), task Interface Manager (n=1), and task Team Manager (n=1).

Task Team Manager (tTM): This role produces design outputs related to a discipline-specific, package-based or time-based task. It is responsible (1) to enforce documentation standards, and (2) to issue approved information within the CDE.

Task team Interface Manager (tIFM): This role manages spatial co-ordination on behalf of a task team and proposes resolutions to co-ordination of clashes. It has the authority to propose resolutions to clashes.

Task Information Manager (tIM): This role directs the production of task information in compliance with standards and methods. Additionally, it directs the production of task information using agreed systems. It is responsible to confirm that information is suitable for issuing within a CDE.

The task BIM-Originator (tOR): This role develops constituent parts of the information model in connection with specific tasks. It generates project outputs. The role holds the ownership of model information.

Table 7. Rotation of roles in UG-teams.

PHASE 1			*PHASE 2*		
tOR	*tIM*	*tTM / tIFM*	*tOR*	*tIM*	*tTM / tIFM*
Student 1 to 4	Student 5, 6		Student 1 to 4		Student 5, 6
		Student 7, 8		Student 7, 8	

PHASE 3			*PHASE 4*		
tOR	*tIM*	*tTM / tIFM*	*tOR*	*tIM*	*tTM / tIFM*
Student 5 to 8	Student 1, 2		Student 5 to 8		Student 1, 2
		Student 3,4		Student 3,4	

4 Implementation of the Pedagogical Methods

Students were assigned to teams as described in the previous sections. Post-Graduate (PG) students were assigned to the Project Teams. PG-students contributed their practical experience and their project management skills to the BIM project. Undergraduate students were assigned to Task Teams.

The class was presented with the overall problem statement in the first week of the term. This was complemented by a guided tour through the building, highlighting BIM-specific features of the building, such as repetitive building components, interfaces between building sections, etc.

For each project phase the class had a dedicated time frame to develop the expected problem solutions. A breakdown is presented in Table 8.

Table 8. Duration of project phases and problems to be solved

	Phase 1	*Phase 2*		*Phase 3*	*Phase 4*	
Duration	2 weeks	4 weeks	*Presentation 1*	2 weeks	4 weeks	*Presentation 2*
UG-Team	Families	Core & Shell Model		Room Model | BEP Phase 4	UFH Model	
PG-Team	BEP Phase 2	Evaluation P2, BEP Phase 3		Evaluation P3	n.a.	

4.1 The Demonstration Project and Tools Used

Since the design capabilities of 2nd year students are still limited we decided to provide students with design drawings of a state-of-the-art university building, namely the building of UCC's Environmental Research Institute (ERI). This building was inaugurated in 2007, has 3 floors (basement, ground floor, first floor) and an approximate usable floor area of 2500 sqm.

The building was designed as a so called green building, i.e. it is equipped with three energy sources for heating, such as solar-thermal panels, a heat pump fed by an open aquifer loop, and a back-up gas boiler.

The superstructure is made of concrete and the façade comprises primarily of wood panels. Offices on the south façade are naturally ventilated and laboratories on the north façade are mechanically ventilated.

Academic staff in collaboration with PhD-students prepared a complete, consistent model documentation, comprising of grids and levels, 2D drawings of the 'core and shell model', a space model and a model of the building services systems. A 3D-represntation of the building is provided in Figure 1 below.

4.2 Physical Model Spaces

The building was divided in different model spaces, such as (1) section, (2) floor, and (3) building.

A section represents the smallest modelling space. Usually, a single BIM-author (also called BIM-originator) is responsible for the development of the model content. The task team interface manager evaluates the quality of the section models before their integration into the floor model.

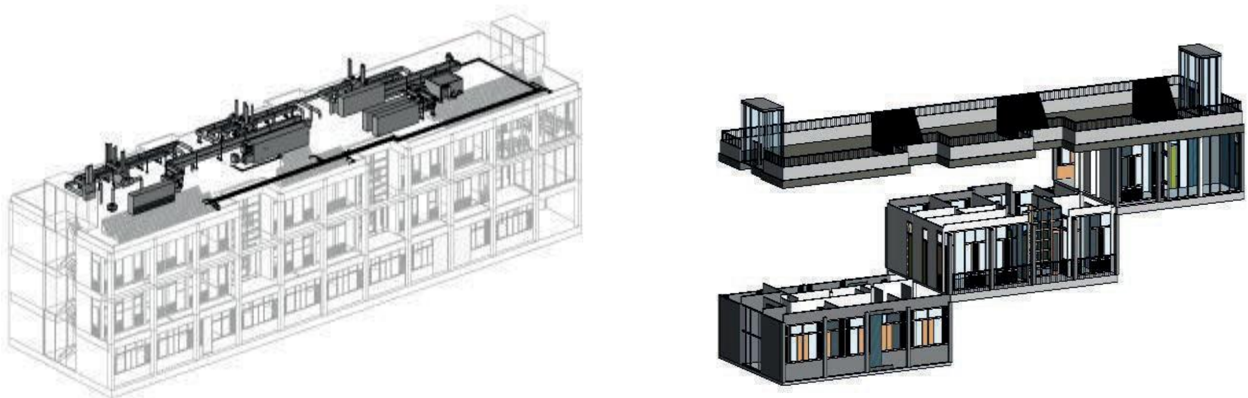

Figure 1. 3D-representation of the ERI-Building (left) and possible breakdown in sections (right).

A floor is a workspace which is allocated to a task team. It is usually broken down into multiple sections (see Figure 1). The horizontal integration of interfaces between (floor) sections is usually executed under the responsibility of a task team. The overall quality (completeness, consistency, integrity) of a floor-model is checked by the project team.

In our scenario, a building represents the largest modelling space. It integrates multiple floors. The vertical integration is usually executed under the responsibility of the project team. Furthermore, the project team was also responsible for the set-up and management of the shared digital workspaces.

4.3 Digital Model Spaces

The management of the digital model space is specified by the rules and conventions laid out in the BIM-Execution Plan (BEP). Furthermore, this document allocates roles to individual team members in the different project phases (see Table 6, and Table 7). It specifies deadlines and the overall structure of a Common Data Environment (CDE).

From an IT-perspective a CDE can be implemented in different ways, e.g. in BIM-Level 2 one can use a federated file system and in BIM-Level 3 one needs to set-up a BIM model server. Irrespectively of the implementation one can distinguish different phases: (1) Work in progress, (2) Shared content,
(3) Published content, and (4) Archived content.

Work in Progress: This is an electronic workspace which is owned by each student acting in the role of a BIM-Author (t-OR). In our scenario an individual BIM-author was responsible for approximately 25% of a floor.

Shared Workspace: Each BIM-author needs to share their work in a dedicated workspace, i.e. the content must be transferred from the "private workspace" into a workspace which is commonly accessible by all members of a task team.

Published Workspace: The tTM has the authority to publish the model, i.e. the model content is shared with the other task- and project teams. In order to achieve this the project teams, represented by the project Design Lead (pDL) assisted by the project Information Managers (pIM) execute the vertical integration process. Before the vertical integration is executed the task Team Manager (tTM) in collaboration with the task Interface Manager (tIFM) checks that the vertically integrated model is complete, consistent, and accurate.

Approved Model: After completion of the vertical integration process (which may need multiple model adjustments) the project Design Lead (pDL) finally "approves" the overall building model. In our project this meant that the model was ready to be submitted for grading. In a "real world project" an approved model is shared with the client, building authorities, or the public.

4.4 Assessment

The Learning Outcomes of the UG-module are (i) to demonstrate the ability to apply knowledge in product and process modelling, (ii) to learn how to work in a design team and (iii) to understand fundamentals of computer graphics, visualisation, and animation. To support the assessment of learning outcomes performance indicators were developed for each learning outcome (see Table 9).

Table 9. UG-learning outcomes and related performance indicators

Learning Outcomes	*Performance Indicators*
(a) to demonstrate the ability to apply knowledge in product and process modelling	1. UG-students can explain the principles of Product and Process Modelling in open BIM (ifc). 2. UG-students understand the concept of "Level of Detail" 3. UG-students have a knowledge of BIM-roles, including their authorities and responsibilities
(b) to learn how to work in a design team	1. UG-students contribute to team meetings and facilitate contributions of other team members. 2. UG-students are able to organise content on task team level, e.g. by maintaining a BIM Execution Plan (BEP). 3. UG-students can articulate design ideas. 4. UG-students are able to evaluate their own design solution. 5. UG-students demonstrate expected work ethics. 6. UG-students convey professionalism.
(c) to understand fundamentals of computer graphics, visualisation, animation	1. UG-students can exploit features of digital modelling environments 2. UG-students can generate relevant representations of the BIM-Model (e.g. floor plans, sections, perspective drawings, etc.)

Learning Outcomes for the PG-course which are relevant for this BIM-project were:
(i) to demonstrate understanding of problems in advanced Building Information Modelling (BIM), (ii) to explain the importance of standardized methodologies for information modelling and retrieval in AEC and FM, and (iii) to analyse interoperable systems for AEC and FM, identify situations of non-interoperability and develop solutions to solve issues of insufficient interoperability. Again, Table 10 shows the mapping of learning outcomes to performance indicators.

Table 10. PG-learning outcomes and related performance indicators

Learning Outcomes	*Performance Indicators*
a) to demonstrate understanding of problems in advanced Building Information Modelling (BIM)	1. PG-students can explain the advanced principles of Product and Process Modelling in open BIM, e.g. objectified relationships or version management. 2. PG-students can deploy their knowledge of BIM-roles, lead project teams and coordinate task teams.
b) to explain the importance of standardized methodologies for information modelling and retrieval in AEC and FM	1. PG-students can lead and coordinate team meetings and facilitate contributions of team members. 2. PG-students are able to organise content on project level, e.g. by developing and implementing a BIM Execution Plan (BEP). 3. PG-students can manage the model content according to different life-cycle phases.
c) to analyse interoperable systems for AEC and FM, identify situations of non-interoperability, develop solutions to solve issues of insufficient interoperability.	1. PG-students are able to evaluate overall design solution including those of peer-students (and inferiors) using standardised openBIM. 2. PG-students can coordinate task teams, propose and request the implementation of model adjustments. 3. PG-students can fully exploit the capabilities of openBIM meta-models for the documentation, quality evaluation and exchange of BIM-models.

5 Results and Reflections

Student performance was assessed by (i) the course instructor, (ii) a guest lecturer from the construction industry, and (iii) an architect with a background in Information Technology. The scope of the assessment included:

a) BIM-knowledge on basic (UG) and advanced level (PG).
b) the ability of students to work in teams (UG) and to use BIM-methods to coordinate BIM-teams(PG), and
c) the capability to present BIM-content (UG) and to analyse and evaluate the content of BIM-models (PG).

Assessment was organised on the basis of student presentations, written reports (e.g. BEP-document), submitted models, instructors' observations (including an analysis of the log-files from the teaching and learning platform used), and written examinations.

5.1 BIM knowledge

A total of five performance indicators (3 UG / 2 PG) were used to determine how well students acquired BIM-knowledge. In the first year UG-students demonstrated difficulties to acquire (theoretical, generic) BIM-principles for Product and Process Modelling. Instead, UG-students were fixated on the development of skills to master the features of a specific commercially available BIM-editor. Only a fraction of the UG-cohort was capable to demonstrate theoretical BIM-knowledge in the written exam at the end of the term (Table 11 2nd row). To balance the emphasis of students' work, on-line quizzes were introduced in the second year, allowing the students to self-evaluate their theoretical knowledge continuously. The results of the written exam improved (see Table 11 last row).

Table 11: Comparison of results from written examination of the UG-module over two subsequent years

	1H	*2H1*	*2H2*	*Pass*	*Fail*	*other*
2015/16	1	3	4	8	14	0
2016/17	4	12	9	9	0	2

In contrary PG-students developed an in-depth understanding of advanced openBIM principles – due to the fact that they had to evaluate the achievements of the UG task teams. Additionally, PG-students also developed a more holistic understanding of all BIM-roles due to the fact that they had to manage their own project team and to coordinate the related task team.

Table 12: Comparison of results from written examination of the PG-module over two subsequent years

	1H	*2H1*	*2H2*	*Pass*	*Fail*
2015/16	7	3	3	2	0
2016/17	4	0	0	0	0

5.2 Ability to work in teams

Six performance indicators were available to assess UG-students' achievements. Two out of the four UG-teams made substantial progress in developing team skills, including communication skills (2015/2016). This was primarily a result of the excellent leadership demonstrated by the PG project teams. Three out of four teams improved dramatically their capability to organise and manage a system of federated files. In the beginning of the project it became quickly transparent that students were not aware of all features of their work environment. Known, less sophisticated instruments for model sharing were used, consumed too much time and dramatically limited the capabilities for sharing model content. In the second year, only a limited number of students fully executed the roles of task InterFace Manager and the task Information Manager. This also led to a wrong perception of the "project Team Manager" role since students took over tasks of the tIFM and the tIM when working in this role. Especially high performing students demonstrated great difficulties to leave their "individual workspaces" and to contribute to an overall team effort (see Table 13 – last row).

Table 13: Comparison results from continuous assessment over two subsequent years (UG-module)

	1H	*2H1*	*2H2*	*Pass*	*Fail*	*other*
2015/16	10	14	6	0	0	n.a.
2016/17	5	17	8	2	2	n.a.

5.3 Ability to use standardised BIM-methods to coordinate BIM-teams

Two performance indicators were available to evaluate this learning outcome on PG-level. In 2015/16 PG-students developed during the project more advanced skills to use common IT-platforms for sharing information amongst team members and between teams. However, simple, non-course related issues, prevented students from using these environments in the early project phases, such as forgotten passwords, limited knowledge of network operating systems, or limited motivation to explore "unknown" solutions for information sharing. Furthermore, the task to develop a BIM-execution plan was perceived by students as a rather "bureaucratic, theoretical" exercise. This perception may reflect a general trend in the construction sector to approach tasks in an "ad-hoc" fashion. It confirms to lecturers that the aspect of structured preparation of BIM-projects needs to be further emphasised and more intensively developed. In 2016/17 PG-students of two project teams made substantial progress over the course of the project to lead and coordinate team meetings.

5.4 Presentation of BIM-content using computer graphics, visualisation & animation

Two performance indicators were used to assess students' performance. Approximately 75% of the student cohort from 2015/16 developed excellent skills in mastering the features of a digital modelling environment (verified by grading of personal presentation). This skill clearly improved over project phases 3 to 4. Similar results can be reported about the development of skills on how to represent a BIM model in different plans and drawings. However, the capabilities to structure the model content according to different phases of the buildings' life cycle were less developed. This might be related to the fact that UG-students were not exposed to ideas of version management in classes (see also Table 13).

5.5 Ability to Analyse and Evaluate BIM-model content

Three performance indicators were available to evaluate PG-students' performance against the achievement of this learning objective. As one can see in the presented comparison of the two academic years (see Table 14), the performance of the PG-student cohort in 2016/17 declined. However, the following should be noticed: (1) the number of students enrolled in the module dramatically decreased from 15 in 2015/16 to four students in 2016/17. This resulted from different sources of funding for places in the MEngSc. Programme. One can also observe that two out of the four students were capable to manage the increased workload. These were students taking the course part-time with strong practical and management expertise. The pass and fail results are the achievements of students who directly progressed from a BE-degree programme to the PG-programme with much fewer management experience.

Table 14: Comparison Continuous Assessment Results over two subsequent years (PG-module)

	1H	*2H1*	*2H2*	*Pass*	*Fail*
2015/16	2	12	0	1	0
2016/17	1	1	0	1	1

6 Summary

The introduction of a split-level (PBL)²-scenario is still a very unique teaching-and-learning arrangement (Menzel, et al., 2006). It could be introduced due to the fact that the main author was in the fortunate situation to be the module coordinator of the UG-Module and the course director of the PG-programme, resulting in limited management overhead when it came to the question how to embed such a complex (PBL)²-scenario into the curricula of two distinct programmes (Menzel & Allan, 2010). Furthermore, the main author would like to thank Dr. Michal Otreba, who progressed as BIM-Manager in industry but decided to maintain a link into the academic world by taking over the post of a Visiting Lecturer. The practical expertise contributed to a realistic set-up of problem specifications and the capability to provide in-depth guidance to students. The improved results of UG-students verify the efforts invested in running a (PBL)²-scenario, especially since the number of "Pass-marks" decreased and the number of "1H and 2H1-marks" increased substantially (see Table 15 and Table 16).

Table 15: Comparison of Final UG-Marks over two subsequent years

	1H	*2H1*	*2H2*	*Pass*	*Fail*
2015/16	1	5	9	13	3
2016/17	3	11	13	5	4

Table 16: Comparison of Final Marks over two subsequent years (PG-module)

	1H	*2H1*	*2H2*	*Pass*	*Fail*
2015/16	7	5	2	1	0
2016/17	2	1	1	0	0

From the perspective of PG-students the high marks in the academic year 2015/16 also demonstrate the outstanding motivation and excellent achievements of PG-students. The authors argue, that the high motivation may have resulted from the fact, that these students could focus on "senior management tasks", as appropriate and expected from MEngSc. students. The BIM-content development and initial management was already executed in the UG-task-teams. Due to the low number of participating students in the Academic year 2016/17 a statistically valid evaluation of PG-students' performance is not possible. Nevertheless, the trend of very good results seems to be unchanged.

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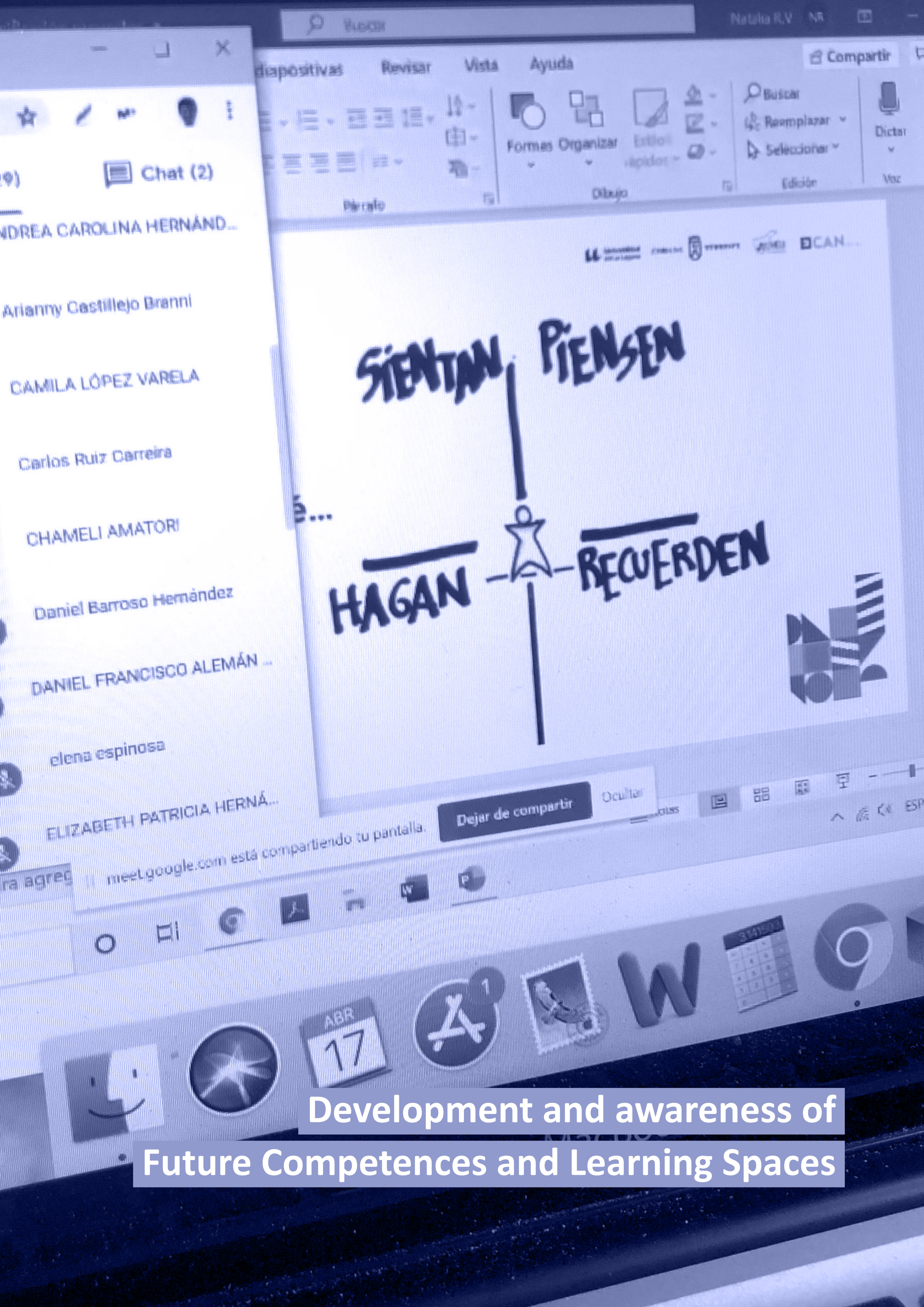

Development and awareness of Future Competences and Learning Spaces

Development of motivation in a problem-based psychology bachelor's program

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Abstract

Problem-based learning (PBL) aims to promote students' intrinsic motivation to learn, but there is little empirical evidence for this claim. In this study, we investigated the development of students' motivation in a three-year PBL curriculum. Different types of motivation were measured at the start of the first year and the end of the first, second, and third year. We examined three indicators of stability and change: correlations, mean-level change, and individual-level change. Correlations showed relatively strong stability across time points. Overall, the mean-level change results indicated that some high-quality motivation types such as intrinsic and identified motivation remained relatively stable while studying in a PBL curriculum. Specifically, results showed that motivation to learn new things (i.e., intrinsic motivation to know) or because reading and the discussions are stimulating (i.e., intrinsic motivation to experience stimulation) declined during the first year, but remained relatively stable afterward. Students' intrinsic motivation toward accomplishments (i.e., pleasure resulting from accomplishing learning goals) and identified motivation (i.e., studying because it is personally meaningful), remained stable throughout the three years. External motivation (i.e., studying to get a high paying job later) did not change through the years. However, introjected motivation (studying out of guilt or shame) and amotivation declined after the first year. Finally, individual level-change was examined with the reliable change index. A pattern of change was found that was different from what we would expect if the change was random. At each consecutive time point, a significant portion of students reported either an increase or a decrease in motivation. These individual increases or decreases in motivation can cancel each other out in the mean-level change analyses. Therefore, in future research, we need to examine why some students become more motivated, whereas others become less motivated while studying in a PBL curriculum.

Keywords: Problem-based learning, intrinsic motivation, extrinsic motivation, longitudinal study, self-determination theory

Type of contribution: PBL research

1 Introduction

Problem-based learning (PBL) is a student-centered educational method in which small groups of students work on meaningful problems under the guidance of a tutor (Barrows, 1996; Schmidt, 1983). One of its instructional aims is to promote students' intrinsic motivation for learning (Barrows, 1986; Norman & Schmidt, 1992; Hmelo-Silver, 2004). It is believed that by introducing students to realistic problems at the start of a bachelor's program will make learning more meaningful and motivating. However, only a few studies have examined the development of motivation in a PBL curriculum (Duman & Şen, 2012; Kocaman *et al.*, 2009; Mert *et al*., 2012). These three studies examined the development of motivation (i.e., feelings of internal control and motivation to learn) in a 4-year nursing program at Dokuz Eylül University, Turkey. Overall, the results from the longitudinal studies demonstrated motivation to learn, and feelings of internal control increased during the first year of a PBL program and remained stable between the second and third years of their study. However, whereas Kocaman *et al*. (2009) showed that motivation to learn increased in the fourth year, internal locus of control decreased at the beginning of the fourth year (Duman & Şen, 2012). As far as we know, no studies have investigated the development of intrinsic motivation in a PBL curriculum. Furthermore, it is unclear if PBL succeeds in its aim to increase students' intrinsic motivation. Some studies that investigated the effect of PBL on intrinsic motivation in a PBL curriculum by comparing it to a lecture-based curriculum found no effect (e.g., Wijnen *et al*., 2017; Wijnia *et al*., 2011). In the current study, we examine the development of students' motivation in a three-year psychology bachelor's program. Motivation is viewed from the perspective of self-determination theory (SDT; Deci & Ryan, 2000; Ryan & Deci, 2017).

1.1 Self-determination theory

In SDT, several types of intrinsic and extrinsic types of motivation have been distinguished that lie on a self-determination continuum (see Figure 1; Deci & Ryan, 2000; Ryan & Deci, 2017). High-quality motivation types are self-determined or autonomous in nature. Autonomously motivated students experience psychological freedom and volition in the activities they undertake. Autonomous motivation can be further subdivided into three types of intrinsic motivation and identified motivation (Vallerand *et al*., 1992). The first type of intrinsic motivation is intrinsic motivation to know. It consists of behavior being performed for the pleasure that is experienced while studying or learning new things. Intrinsic motivation to accomplish things refers to engaging in an activity for the pleasure that is experienced when one tries to accomplish things, such as mastering learning goals. Finally, intrinsic motivation to experience stimulation reflects behavior being performed to experience stimulating sensations, for example, studying because the readings and group discussions are interesting. In addition to the three types of intrinsic motivation, also identified motivation is a form of autonomous motivation (Deci & Ryan, 2000). Students with identified motivation perform an activity because they believe the task is vital for obtaining personal life goals or personal growth. Although this is an extrinsic type of motivation, if students find an activity personally meaningful, they can volitionally engage in the activity and will experience self-determination (Deci & Ryan, 2000).

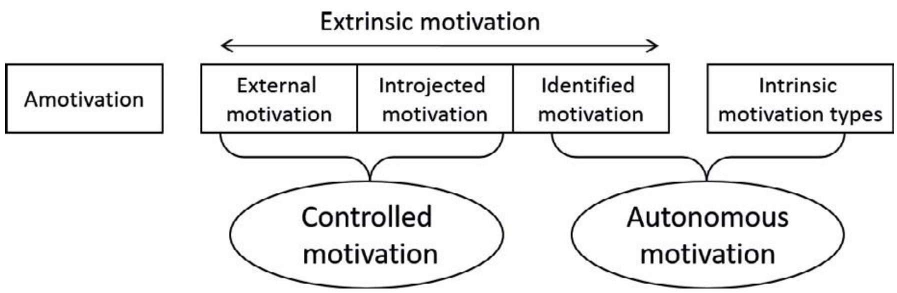

Figure 1: Self-determination continuum (see Deci & Ryan, 2000)

Low-quality motivation types are controlled in nature, meaning that these students experience pressure from within or from an external source (Deci & Ryan, 2000). Introjected motivation consists of behavior that is regulated by internal coercion, such as guilt or shame. External motivation reflects behavior that is regulated by an external contingency. In addition to autonomous and controlled motivation, students may experience amotivation (Deci & Ryan, 2000). If students are amotivated, they have no reason to engage in the activity.

1.2 Intrinsic motivation in PBL

An important instructional aim of PBL is to increase students' intrinsic motivation (Barrows, 1986; Norman & Schmidt, 1992; Hmelo-Silver, 2004). PBL has its origins at McMaster University (Canada) and was introduced in an attempt to reform medical education. By introducing students immediately to patients and their problems from the start of the program, it was expected that learning would become more meaningful and intrinsically motivating (Servant-Miklos, 2019; Spaulding, 1969). Several aspects of PBL are considered motivating, such as working with meaningful real-life problems, student-centered learning that allows learners to take control over their learning process, and collaborative learning. Research has shown that these factors can indeed foster motivation (Ames, 1992; Black & Deci, 2000; Blumenfeld, 1992; Deci & Ryan, 2000; Katz & Assor, 2007; Norman & Schmidt, 1992). However, several studies have reported on motivational problems that occur in group meetings or have failed to find empirical support for the motivating effects of PBL (Dolmans & Schmidt, 2006; Galand *et al*., 2010; Wijnen *et al*., 2018; Wijnia *et al*., 2011). Students have mentioned uncertainties about what to study and lack of variation in the process of tackling problems as demotivating aspects of PBL (Wijnen *et al*., 2018; Wijnia *et al*., 2011). Furthermore, no differences in autonomous motivation were found between PBL students and students in a lecture-based program (Wijnen *et al.*, 2018; Wijnia *et al.*, 2011). Because measurement at one time point does not give a good indication about the effect of PBL on motivation, we wanted to examine the stability and change of PBL students' (intrinsic) motivation in a three-year PBL program.

1.3 Indicators for the stability and change in motivation

Several indicators can be used to examine the stability and change in students' motivation. *Differential continuity* is the most common type of analysis that has been used to analyze stability and change over time (Fryer & Elliot, 2007). It represents the level of rank-order consistency within a sample of a construct over time and is measured with Pearson product-moment correlations. Correlations of .10 can be interpreted as small, .30 as moderate, and .50 as large (Cohen, 1988). Another type of indicator is *mean-level change*. A mean-level change concerns the degree to which the average of a score on a construct changes over time within a sample (Fryer & Elliot, 2007). It can be measured with a repeated-measures ANOVA or paired *t*-tests.

Differential continuity and mean-level change both indicate change at the sample level. However, it is also interesting to examine stability and change at the individual level (Fryer & Elliot, 2007). *Individual-level change* represents the magnitude of an individual students' increase or decrease in motivation over time and yield information independent of the information provided by differential continuity and mean-level change. The reliable change index (RCI) can be used as an indicator of individual-level change by differentiating between statistically significant change and change due to measurement error (Christensen & Mendoza, 1986; Fryer & Elliot, 2007; Jacobson & Truax, 1991). It can be calculated by dividing the difference in Time 1 and Time 2 by the standard error of the difference score. Values smaller than -1.96 or larger than 1.96 are considered an indicator of reliable change. It is possible to aggregate these data to make summary statements about reliable change within the sample of students as a whole by examining the percentage of people showing a decline, increase, or no change between time points. Under a normal distribution, we would expect that 95% of the values are between -1.96 and 1.96 (no change), whereas 2.5% below -1.96 (decrease) and 2.5% above 1.96 (increase) if change is random.

1.4 Present study

In the current study, we examined the stability and change in students' motivation in a three-year PBL psychology program. In this program, the PBL format is a constant factor for all courses taken by students. To ensure continuity, all teachers and coordinators in the program receive PBL training before and during teaching courses. In the PBL environment, students work in small groups of maximally 13 students. Students meet twice a week, in which they work with the Seven Jump method (Schmidt, 1983). After students read the problem description, they perform an initial problem discussion consisting of five steps: 1) clarification of unfamiliar terms, 2) formulating a problem definition, 3) brainstorm, 4) problem analysis, 5) formulation of learning goals for next meeting. After this meeting, students have 2-3 days for self-study (step 6). After the self-study phase, students have a reporting phase (step 7), in which they share what they have learned and apply it to the problem.

Different types of motivation were measured at the start of the first year (T1) and the end of the first (T2), second (T3), and third year (T4). We examined the differential continuity, mean-level change, and individual-level change in scores. We did not have specific hypotheses about the development of motivation in the PBL curriculum due to the conflicting results of prior research on the effect of PBL on (intrinsic) motivation. However, we want to point out that increases in high-quality motivation types (i.e., three intrinsic types and identified motivation), and decreases in low-quality motivation types (i.e., introjected and external motivation) and amotivation, are viewed as positive effects of PBL.

2 Method

2.1 Participants

Our participants are three cohorts of students enrolled in a three-year PBL psychology bachelor's program in the Netherlands (N = 881; 72.87% female). On average, students were 19.84 (SD = 2.97) years old at the start of their study program. All students were invited to participate in the study. Measurements took place at the start of the first year, at the end of the first year, at the end of the second year, and at the end of the third year. Not all students participated at all time points (T1: n = 736, T2: n = 603, T3: n = 602, T4: n = 602), for example, due to attrition from the study program or not being present during measurement. Two hundred ninety-four students completed all four measurements. Participation was voluntary, and students gave informed consent regarding the use of their questionnaire for research purposes.

2.2 Academic motivation scale

Students' motivation was measured with the academic motivation scale (AMS; Vallerand *et al*., 1992). The AMS is based on SDT and has been proven to be a reliable and valid (construct, convergent, and discriminant validity) instrument (see Fairchild *et al*., 2005). It consists of 28 items that reflect possible answers to the question, "Why do you go to college?" and measures the motivational constructs proposed by SDT: amotivation, external, introjected, identified, and intrinsic motivation. However, the AMS breaks down the unified construct of intrinsic motivation into tree subscales of intrinsic motivation: intrinsic motivation to know, to accomplish things, and to experience stimulation. Intrinsic motivation to know consists of behavior being performed for the pleasure that is experienced while studying or learning new things (e.g., "because I experience pleasure and satisfaction while learning new things"). Intrinsic motivation to accomplish things refers to engaging in an activity for the pleasure that is experienced when one tries to accomplish things (e.g., "for the experience when I discover new things never seen before"). Intrinsic motivation to experience stimulation reflects behavior being performed to experience stimulating sensations (e.g., "for the intense feelings I experience when I am communicating my own ideas to others").

Three other subscales reflect extrinsic reasons for going to college: identified, introjected, and external motivation. The subscale identified motivation consists of behavior that is valued and is experienced as chosen by oneself (e.g., "because I think that a college education will help me better prepare for the career I have chosen"). The introjected motivation subscale consists of behavior that is regulated by internal coercion, such as guilt or shame (e.g., "to prove to myself that I am capable of completing my college degree"). In contrast, external regulation reflects behavior that is regulated by an external contingency (e.g., "because with only a high-school degree, I would not find a high-paying job later on"). Amotivation is measured with the seventh subscale (e.g., honestly, I don't know; I really feel that I am wasting my time in school"). Responses are measured on a 7-point Likert-type scale ranging from 1 (*does not correspond at all*) to 7 (*corresponds exactly*). Table 1 depicts the reliability of the constructs at each time point (T), using McDonald's omega ($\omega\omega$). The reliability was satisfactory except for identified motivation.

Table 1: Reliability of the motivation constructs (McDonald's omega).

	T1	T2	T3	T4
Intrinsic motivation to know	.876	.849	.840	.858
Intrinsic motivation to accomplish things	.832	.841	.824	.847
Intrinsic motivation to experience stimulation	.808	.797	.833	.833
Identified motivation	.617	.585	.564	.643
Introjected motivation	.871	.876	.884	.890
External motivation	.772	.773	.787	.794
Amotivation	.895	.865	.896	.907

3 Results

3.1 Differential continuity

We used correlations to examine the differentiation continuity of each motivation construct across the four time points (see Table 2). The correlations ranged between .310 and .764. Correlations were stronger at consecutive time points. Thirty of the 42 correlations could be interpreted as large (r > .50), the other correlations were moderate (r > 30). When examining the correlations at T1-T4, stability was most robust for external and introjected motivation and less robust for amotivation and identified motivation.

Table 2: Differential continuity of motivation (correlations)

	T1-T2	T1-T3	T1-T4	T2-T3	T2-T4	T3-T4
Intrinsic motivation to know	.599	.476	.479	.570	.531	.646
Intrinsic motivation to accomplish things	.555	.523	.370	.614	.527	.576
Intrinsic motivation to experience stimulation	.592	.528	.486	.656	.610	.639
Identified motivation	.487	.414	.361	.506	.449	.598
Introjected motivation	.683	.642	.597	.716	.669	.764
External motivation	.657	.586	.560	.674	.612	.724
Amotivation	.459	.365	.310	.627	.485	.592
n	535	467	372	443	362	358

Note. All correlations are significant at the p < .001 level.

3.2 Mean-level change

The mean-level change was investigated with a repeated-measures ANOVA (see Table 3). Mean-level change with a *p*-value less than .05 was considered statistically significant. Only the students with complete data were included ($n = 294$). When we examine the high-quality motivation types, we found that students' intrinsic motivation to accomplish things and identified motivation remained stable during the three-year bachelor's program. The other two types of intrinsic motivation did show decreases, especially during the first year of the program. Specifically, intrinsic motivation to know declined significantly from T1 to T2 (p = .002) and was higher at T1 relative to T3 and T4 ($p < .001$). Intrinsic motivation to know remained stable between T2 and T3 (p = 348) but declined again between T3 and T4 (p = .022). Also, intrinsic motivation to experience stimulation declined significantly from T1 to T2 ($p < .001$) and was higher at T1 relative to T3 (p = .019) and T4 (p = .001). However, this type of motivation remained relatively stable from T2 to T4.

When we examined the low-quality motivation types, we found that introjected motivation remained stable between T1 and T2 (p = .062). Further analyses revealed that students' at T1 did report higher introjected motivation than at T3 and T4 (*p*s < .001). Furthermore, the decline in introjected motivation between T2 and T3 was significant (p = .002) and remained stable between T3 and T4 (p = .940). The decline in introjected motivation from T2 to T3 is positive, as it indicates students feel less regulated by feelings such as shame or guilt. External motivation remained stable during the three-year bachelor's program. Finally, students' amotivation was similar at T1 and T2 (p = .714), but increased afterward (from T2 to T3, p = .001, from T3 to T4, p = .005).

Table 3: Mean-level change (repeated measures ANOVA, n = 294)

	T1	T2	T3	T4		
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*F*	η_p^2
IM to know	5.88 (0.82)	5.75 (0.77)	5.72 (0.73)	5.63 (0.79)	3.28***	.039
IM to accomplish things	5.03 (1.01)	5.04 (1.02)	4.95 (0.98)	4.95 (1.00)	1.44	.005
IM to experience stimulation	4.98 (0.98)	4.80 (0.97)	4.86 (1.02)	4.77 (1.04)	6.69***	.022
Identified motivation	5.50 (0.77)	5.52 (0.74)	5.60 (0.74)	5.56 (0.83)	2.06	.007
Introjected motivation	4.90 (1.31)	4.78 (1.26)	4.60 (1.38)	4.60 (1.39)	10.88***	.036
External motivation	5.01 (1.16)	5.01 (1.09)	5.10 (1.06)	5.03 (1.11)	1.05	.004
Amotivation	1.44 (0.79)	1.42 (0.65)	1.55 (0.83)	1.68 (1.01)	11.78***	.039

Note. IM = Intrinsic motivation. Greenhouse- Geisser correction is reported. *** $p < .001$.

3.3 Reliable change

RCIs were calculated to determine whether individual students showed reliable changes in motivation between time points. These RCIs were then aggregated for the sample to indicate the percentages of students who showed a reliable increase (+), decrease (-), or no change (same) at each of the three consecutive time comparisons. These percentages are reported in Table 4. As mentioned, under a normal distribution, we would expect that 95% of the values are between -1.96 and 1.96, whereas 2.5% of the values are below -1.96 and above 1.96; meaning that scores higher than 5% are statistically significantly greater than a difference occurred due to random measurement error alone. As demonstrated in Table 4, each motivation construct showed a pattern of change that is different from what we would expect if the change was random.

Table 4: Reliable change in motivation (in percentages)

	T1-T2			T2-T3			T3-T4		
	-	same	+	-	same	+	-	same	+
IM to know	52.7	17.9	29.3	41.3	20.1	38.6	46.1	22.1	31.8
IM to accomplish things	44.9	12.5	42.6	44.9	16.7	38.4	42.7	13.7	43.6
IM to experience stimulation	54.6	14.2	31.2	40.0	15.3	44.7	41.6	14.0	44.4
Identified motivation	43.9	13.1	43.0	37.0	16.0	47.0	45.0	15.4	39.7
Introjected motivation	47.1	13.3	39.6	51.7	11.1	37.2	45.0	12.8	42.2
External motivation	45.6	14.4	40.0	42.2	14.7	43.1	45.8	15.9	38.3
Amotivation	22.8	45.4	31.8	22.1	43.4	34.5	25.4	41.9	32.7
n		535			443			358	

Note. IM = Intrinsic motivation.

When we examine the high-quality motivation types (i.e., three types of intrinsic and identified motivation), we can see that from T1 to T2 (beginning of the first year to the end of the year), a higher percentage of students showed a decline in motivation. These percentages for decline ranged between 43.9% and 54.6%. However, a significant proportion of students increased in high-quality motivation (range 29.3%-43.0%). When we examine the reliable change from the end of year 1 to the end of year 2 (T2-T3) and from the end of year 2 to the end of year 3 (T3-T4), this pattern is less pronounced. Table 4 demonstrates that a higher percentage of students reported increases rather than decreases in identified motivation and intrinsic motivation to experience stimulation from T2 to T3. For T3 to T4, a higher percentage of students showed increases rather than decreases in intrinsic motivation to accomplish things and to experience stimulation.

For the low-quality controlled motivation types (i.e., introjected and external motivation), a higher percentage of students tended to show a decrease in motivation than an increase. Decreases in controlled motivation are positive, as this indicates that students' experience less pressure. For amotivation, between 41.9%-45.4% of students did not show a change in amotivation across time points.

4 Conclusion and discussion

In this paper, we examined the development of students' motivation in a three-year PBL bachelor's program. One of the instructional aims of PBL is to increase students' intrinsic motivation to learn (e.g., Barrows, 1986). However, empirical support for the positive effect of PBL on intrinsic motivation relative to lecture-based environments is lacking (e.g., Wijnia *et al*., 2011). To examine the development of motivation, we examined three indicators of stability and change: differential continuity, mean-level change, and the reliable change index. Students' motivation was seen from an SDT-perspective. SDT makes a distinction between high-quality, autonomous motivation (i.e., intrinsic motivation types and identified motivation), low-quality, controlled motivation (i.e., external and introjected motivation), and amotivation (Deci & Ryan, 2000; Vallerand *et al*., 1992).

Overall, the results of our study provide clear evidence for both stability *and* change in motivation. When we look at differential continuity, we found moderate to strong stability in motivation across time points (range r = .310-.764). The differential continuity appeared to be stronger for external and introjected motivation, and lower for amotivation and identified motivation, with intrinsic motivation types falling in between. All correlations were lower than .80; this indicates that motivation also changes across time points.

The mean-level change analyses suggested statistically significant changes in four of the seven motivation constructs. Concerning intrinsic motivation, motivation to learn new things (i.e., intrinsic motivation to know) or because reading and the discussions are stimulating (intrinsic motivation to experience stimulation) declined during the first year but remained stable during the second year. Intrinsic motivation toward accomplishments, referring to the pleasure students experience while they accomplish their learning goals, remained stable throughout the three years. Also, identified motivation (studying because it is personally meaningful) remained stable throughout the years.

Concerning low-quality, controlled motivation types, external motivation (studying to get a high paying job later) remained stable throughout the years. Introjected motivation (studying out of guilt or shame) did not change in the first year, but declined from the end of year 1 to the end of year 2, and remained stable after that. These results indicate that over the second year, students were less regulated by feelings of guilt or shame. Also, amotivation remained stable during the first year but increased after the end of the first year. However, scores in amotivation were relatively low across all time points.

Differential continuity and mean-level change indicate change at the sample level, whereas it does not tell us about the change or stability in motivation for individual students. Therefore, we calculated the reliability change index to extend the results of the mean-change level analyses. When examining reliable change, we found that each motivation construct showed a pattern of change that is different from what we would expect if the change occurred at random. Across consecutive time points, 22.1% to 54.6% of students showed a decrease in motivation, whereas 29.3 to 47.0% of students showed an increase. A decrease in low-quality motivation is a good sign, but declines also occurred for high-quality motivation types. For most motivation constructs, the percentage of students showing a decrease was higher than the percentage of students showing an increase. Nevertheless, a significant percentage of students reported an increase in motivation.

In sum, the mean-level analyses did not support the claim that PBL leads to increases in students' intrinsic motivation toward studying. On a positive note, at least two of the four high-quality motivation types remained stable (i.e., intrinsic motivation to accomplish things and identified motivation). Furthermore, it is a good thing that studying out of feelings of shame and guilt declined between the end of the first and second years. However, a more nuanced picture appears when looking at individual patterns of stability and change using the reliable change index. Because both significant proportions of increase and decrease were found, this indicates that possibly individual increases or decreases in motivation cancel each other out in the mean-level change analyses. This suggests that in future research, it is fruitful to take a person-centered approach to data-analyses and examine if different subgroups of students can be identified who show different patterns of change and stability in motivation. This suggestion for future research could be seen as a limitation of the current study. Still, at the same time, the results provide a first insight into the stability and change in intrinsic motivation in a PBL environment.

Furthermore, in our study, we only investigated the development of students' motivation in a PBL environment. It is unclear if a similar pattern of stability and change would be found for students' in a lecture-based environment. To date, not many studies investigated the stability and change in motivation in higher education. Future research in which students from multiple types of learning environments (e.g., PBL and lecture-based learning) are investigated will provide more insight into the development of students' motivation and the role of the learning environment in this process. Nevertheless, examining stability and change in PBL is important because PBL environments are designed to be intrinsically motivating (Barrows, 1986; Norman & Schmidt, 1992; Hmelo-Silver, 2004).

Finally, it is important the investigate which factors within PBL curricula determine why some students increase or decrease in motivation. Specific individual characteristics may determine how students experience the PBL curriculum. For example, Noordzij and Wijnia (2020) showed that individual differences in students' achievement goal orientation influenced the perception of the quality of PBL problems, and this subsequently affected students' motivation to learn. Therefore, future studies could examine individual differences or other factors that affect students' development of motivation in PBL.

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The Role of Teamwork on Students' Engineering Professional Identity Development in the AAU PBL Model: From the Perspectives ofInternational Engineering Students

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Abstract

Engineering identity has been seen as a significant indicator for engineering students' persistence and competence development. In order to develop students' engineering professional identity, PBL has become an effective learning method because it provides a pathway for engineering students to experience solving real-world problems as real engineers. Among various PBL implementations, the PBL Model in Aalborg University has been practiced over decades. Previous studies have evidenced benefits of PBL on local students regarding problem-solving skills, teamwork skills and leadership. However, it has also been reported that PBL can be challenging for international students who come from educational backgrounds that focus on lectures and individual learning and who had no prior PBL knowledge and experiences. It's important to clarify how international students perceive and how AAU PBL model contributes their engineering identity development. Thus, this study explores major components of engineering identity developed by international students during their study in the AAU PBL model, compared with their pervious learning experiences. Methodologically, a qualitative method with six first-year international engineering students in their Master study participated in the semi-structured individual interviews. Compared to lecture-based traditional learning, students reported that they improved their confidence, interest in engineering, transferable skills and understanding of teamwork and engineers' responsibilities through AAU PBL experiences.

Keywords: PBL; International Learning experience; Engineering Identity; Teamwork

Type of contribution: PBL research

1 Introduction

Engineering talents of the 21^{st} century are not only expected to have academic knowledge and technical skills, but also need practical experiences and diverse competences, such as problem-solving skills, teamwork skills, and self-learning skills (UNESCO, 2017). With these demands of future engineers, project/problem-based learning (PBL) has become an effective learning method to develop students' competences of solving complex problems, collaboration, team management and leadership (De Ríos-Carmenado et al., 2015). By exposing students to complex, real-world, and multidisciplinary problems, PBL provides students a pathway to work as real engineers to gain practical experience and builds a bridge for the gap between university and industry. Students with PBL experiences are reported to have better preparation for future engineering job and develop higher levels of engineering identity (Du, 2006; Yadav et al., 2011). With the benefits of PBL on training engineering talents, PBL methods have been widely used in engineering education (Chen, Kolmos & Du, 2020). Among various PBL implementations, the PBL model in the Aalborg University (AAU PBL model) has been developed and practiced over three decades. In the AAU PBL model, each semester is organized with 50% course work (15 ECTS) and 50% project work (15 ECTS) in teams, where students work together on real-world and complicated problems and finish their semester reports. Many researches provide evidence on benefits of the AAU PBL model on local students regarding students' development of problem-solving skills, teamwork skills, self-directed learning and leadership (Kolmos & Holgaard, 2019; Guerra & Kolmos, 2011). Graduates from AAU were reported with higher levels of engineering identity and received higher levels of employer satisfaction (Clausen & Andersson, 2019; Kolmos & Holgaard, 2015).

However, transferring from traditional learning methods to PBL methods is a challenging job, especially for students without PBL or teamwork experiences (Huang, 2011). In AAU, many international students, who may come from educational background that focus on lectures, are facing the challenge of adapting PBL methods and collaborative learning. Prior studies explored international students' learning experiences as foreigners with culture differences in the Danish context and pointed out identity change through learning processes is an important learning outcome in PBL (Du & Hansen, 2005). For further understanding of the influence of PBL on international students' engineering identity formation, it's important to explore what PBL means to those international students and how AAU PBL model contributes to their development as future engineers. Thus, this study focuses on processes of international students' engineering identity development via AAU PBL model, and aims to answer the following research question: From international students' perspectives, compared with their pervious learning experiences, what major components of their engineering identity have been developed under the AAU PBL model?

2 Theoretical Framework

To explore engineering identity with a clear structure, this study adopts Godwin's (2016) model of engineering identity as theoretical framework, with three dimensions of performance, recognition and interests. Performance refers to students' belief and ability to achieve learning goals and understand engineering content. Recognition means that students could get recognition from peer, parents or teachers as being good engineering students. The last component, interest means students' desire and curiosity to explore professional fields, which motivate students to learn knowledge and skills. Godwin pointed out that engineering identity was developed through interactions with others in the community of practice, but this model mainly from individual perspectives or focus on individual learning processes. Thus, in order to catch the missing link between engineering identity development and interactions in communities, this research use this framework to investigate engineering identity development in a PBL context. Although Godwin's (2016) model of engineering identity focuses on individual learning processes, it still can provide us a structured perspective to explore students' engineering identity development in teamwork processes. With guidance of Godwin's (2016) model, this study reports how AAU PBL model contributes to international students' engineering identity formation and development, which could enrich our understanding on engineering identity from the perspective of team learning processes and inspire the optimization of PBL design to improve learning experiences and learning outcomes of students without previous PBL or collaborative learning experience.

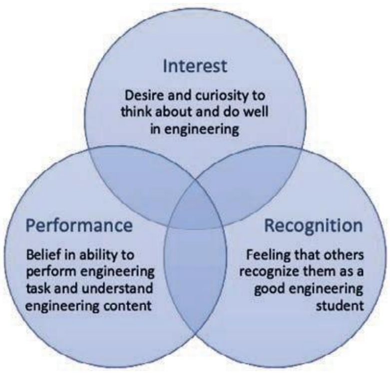

Figure 1: Godwin's model of engineering identity (2015; 2016)

3 Methodology

This study adopted a qualitative method. Empirical data were collected through individual semi-structured interviews. With the perspective of teamwork and the guidance of Godwin's model of engineering identity, an interview protocol with dimensions of performance, recognition and interest was designed. Then the interview protocol was tested and revised through three rounds, including descriptive questions like "Could you describe briefly how you collaborate with your team members to finish the projects?" and questions in three dimensions, such as "What do you learn from this PBL and teamwork experience?", "In which ways you consider yourself as a future engineer?", "In which ways your current study has helped you develop such as sense of feeling as an engineer?", "What differences do you find between PBL experience you're your prior study?" and so on. In the process of collecting data, purposeful sampling was employed in recruiting international engineering students with PBL experiences in AAU as interviewees. Six international engineering students who finished their bachelor's study in their home countries and now are in the first semester of master's study in AAU were recruited (Table 1).

In this study, interviews were conducted in English and transcribed carefully, and every interview lasted 30-40 minutes. For the sake of privacy protection, pseudonyms are used in the transcripts for all interviewees. In order to build a structured codebook, the three dimensions in Godwin's model were identified as the initial categories in the first step. Then open-coding and thematic analysis methods are used to identify both theory-driven and bottom-up codes, which enables us to come up with new characteristics of identity development in PBL processes. The initial codebook was built upon analyzing three transcripts with rich information, constituting a relatively stable frame for coding (MacQueen et al., 1998). To enhance the validity of data analysis, daily journaling, self-monitoring and auditing procedures were conducted to refine the codes in data analysis processes (Cresswell, 2009). A revised codebook was formed through this process and then used for data analysis.

Table 1: The basic information of participants.

Name	Gender	Nationality	Subjects
Ivy	Female	Croatia	Energy engineering
Daisy	Female	Croatia	Mechanic engineering
Gina	Female	Hungary	Energy engineering
Carl	Male	China	Electronic engineering
Ken	Male	Croatia	Energy engineering
David	Male	Portugal	Energy engineering

4 Findings

With the guidance of the engineering identity model, we analyze and scrutinize evidence of how AAU PBL model contributed to international students' engineering identity and what differences they reported between their previous learning experiences and PBL experience in AAU. Part of our preliminary findings in the dimensions of performance, recognition and interests are presented as follows.

4.1 Performance

Link theories to practice

Based on qualitative data, all six international students reported that one of the most important change in their study was the chance to link theories to practice in PBL. In their previous study, theoretical knowledge was mainly learned through lectures and lab work. What they were required to do mostly focused on memorizing and understanding those theories, where they had a few chances to apply the knowledge into practice. When they conducted PBL in AAU, they were exposed to the real-world problems and learned to work in teams as engineers. It's challenging for these PBL beginners because they needed to identify core problems and directions of possible solutions by themselves, which gave them an opportunity to apply the theoretical knowledge they learned in their home universities in their projects. As Ken said, the most important reason he chose AAU to pursue a master degree and what helped him most is PBL, which enabled him to consider things not only from the perspective of theories but also from angles of real life, including the needs of clients, the cost, the influence of environment and so on. In his opinion, those PBL experiences in AAU could help him know more about the ways of engineers' work.

> "I think the **biggest reason why I came here is the PBL**. It is really something else, the problem-based learning, because actually you deal with the tangible projects, and **you actually see what components you need to think about in real life**. Because **in theory, we assumed a lot, and we didn't care about many things before**....**PBL broadens my horizons** in engineering, because when I was only in theoretical learning, I only saw the one solution, but now when I'm in the practical one, I can **see that the solutions are many**. It's only the matter of choice, which you take if you want to, for example, take the at least expensive thing, or just to put it work, or you want some middle solution between the cost, effectiveness, efficiency, or if it is an eco-friendly product. But when you do the theoretical solving of the problems, it's always one and it's a number on that. But actually, a lot of things are should be important." Ken

In Daisy's case, she pointed out that PBL provides a real-life situation, where they needed to decide everything by themselves instead of told what to do. This real-life connection is also a way to conduct professional practice, which is also an important role element for professional identity building (Patrick et al., 2017). With those practical experiences, she thought that she would adapt her job more quickly after graduation from AAU more quickly than graduating from her home university.

> "We can combine the project with the theory learned from Croatia, and now this like a real-life situation with working in a group on a project, and you don't know where to start. You just have a piece of paper with some text, and you have to build something from that. I think **that's a great practice for future, for the company**, for everything. And I think **if I finish like the college in Croatia, I would come to my workplace and I would be like: ok, so can you show me what to do now? But now with this experience, I could come here and immediately I guess where the inputs** of this, this, this, and **start to** work on something or research for starters." Daisy

David shared his project experience in his home university in Portugal and compared the differences with AAU PBL model. Although he had projects to finish in his bachelor's study, the problems were well-structured problems and repeated every year, which made it possible to "copy" others' answers. When he and his group members conducted projects in AAU, to solve those real-life, open-ended and ill-structured problems, they became the center of learning and needed to identify the direction of their projects because in real life of engineers, no one will give them the answers or solutions directly. He further understood the importance of self-directed learning and necessity of being responsible forhimself.

> "**In Portugal, the projects that we are used to do is just like the repeating what students did the last year.** So, you would ask for an older guy: can you just send me your project just to see what have you done? **And we would do the same thing that he had done, but with a different calculation of different values. But the reasoning would be the same, and it was not our reasoning**. It was the older, older, older guy's reasoning. So, **learning and thinking independently is one of the things that PBL brings me to here, at the AAU, because you have no answer to copy and you need to be responsible for yourself**, totally different from my prior project experience. I know the ranking of engineering subjects, and AAU is the first in Europe, the fourth in the world in engineering. I think that PBL is the most reason to be here." David

Improve generic skills

Compared to traditional learning methods, students got more chance to develop their generic skills in PBL. All six students reported their teamwork skills and communications skills have been improved. Four students pointed out the development of their problem-solving skills, two students emphasize the importance of emotion management skills, and two students reported the improvement of their time management skills. One student also mentioned the development of his interdisciplinary skills. With this simulation of working as engineers, they realized the importance of those transferable skills in PBL and could practice those abilities in teamwork processes. For example, in Carl's case, PBL inspired his thoughts about the meaning of teamwork and how to work as a real team. During the PBL processes, to reach effective teamwork, Carl saw the importance of communication and idea sharing, which he did not practice too much in his home university. He learned a lot from his team members with more practical experiences and began to look at things from other angles. Moreover, he pointed out the responsibilities of engineers were not limited in engineering, but also included knowledge from other subjects, and engineers could utilize all those knowledge and skills in their projects.

> "In China, we had heated competition and almost everyone studies alone. Even though we had projects, we just divided the tasks and didn't care about others' parts. But now, **I need to learn how to work in a real team, not just dividing the tasks**. How to integrate into a new team? How to do things in professional and effective ways? How to deliver your idea to others? Engineers need not only to do engineering stuff, but also to care about all aspects of the products, including business promotion, aesthetic values and so on….I also realize that I need to share what I do with others, and others also share their experience and ideas with me. We have a team member who is 26 years old and has working experiences. He teaches us a lot because he has broader horizon than us and know more about practical things, including using professional software, different angles to look at things and solve problems, a better way to express your opinions…" Carl

In addition, Carl also assessed himself with better time management skills in PBL than before. When conducting projects alone, he tended to procrastinate and put things to be done to the last minutes. However, a team as a whole would exert pressures on individual members, influence their thoughts, identity and actions, and also affect team cohesiveness and productivity (Lewin, 1939). In PBL context, in order to avoid troubling other team members and keep pace with their schedule, Carl realized the importance of finishing tasks on time and tried to improve his skill on time management.

> "**When I work alone to finish a project, I was always procrastinating**. My bad habit was that I would not work unless the deadline is coming. But it become better in teamwork. You are required to finish your tasks and communicate with your team members, otherwise you could hinder the whole team and influence others' work negatively, which brings me the pressure to do things on time**. You're not just responsible for yourself, but also for all members in your group**. So, now I **understand the importance of team management** and **enjoy the feeling of finishing things in advance**. I can say I'm better at managing my time." Carl

4.2 Recognition

Get confidence from others' recognition

Among all students, two students reported that PBL boost their confidence because of the recognition from their peers and supervisors. With many interactions with team members and supervisors in project processes, students could be encouraged by positive feedback from others. In Gina's case, she found a problem which did not be identified by others, and her supervisor praised her as a smart engineering student, which made her feel more confident and encouraged her to show more active performance in teamwork processes. Similarly, Carl also pointed out PBL as an important pathway to build confidence and inspire enthusiasm of engineering because finishing a real-world project brought him the sense of achievement.

> “I found a problem and discussed with our supervisor, and he didn’t answer me at that time. But in our next group meeting, he said: ok, so last week we had a very smart students to find out something, so I just want to show you the solution for that. I **felt really very good at that moment**, I mean that's the best engineers university and all of the people are so smart, and it just felt so good that I was the only one who found out that thing. It doesn't happen so frequently, so I felt very good, and it **encourages me to be more active in our group**.” Gina

> “**PBL is a good way to build confidence and gain recognitions** because you’re really creating something. When you finish the project, no matter how hard the process is, you will have a great **sense of achievement**. And we also got very **positive feedback from our supervisor**, so I **felt encouraged and can’t wait to the next project**.” Carl

Realize the benefits of PBL for future engineering job

All participants involved in this study did not experience PBL in their previous learning experience, and they were in their first projects when the interviews were conducted. Based on qualitative data, all six students reported that they could see the values and benefits of PBL, which help them better prepare for future engineering jobs. As what Ivy said, AAU PBL model provided students with an imitation of real engineers’ work, where they learned practical experience and skills and enhanced their feeling of future engineers. Ken also pointed out that through working on real-world projects, he experienced how engineers work by himself, which was the unique advantages of AAU PBL model in building students’ career path. These PBL experiences equipped him with a good engineering background for future job.

> “I think the **group work and project could help me for future engineering jobs**. That is really important and it's very helpful. I’m happy that I **get more relevant experience**, working in a group than I would get if I was working and learning alone. I believe that in the future, at a future job, I won't be working completely alone. At times that I'm pretty sure that it's more going to be working in a group, smaller group or a bigger group, or team working on a project, just like we are now. So, I think that's **a good imitation** of that. **Working with others in AAU is more like working as a real engineer**. It did give us the feeling of that because we're working on a project where solving a problem by ourselves, and in the end, we're going to do something that has a specific function and it's going to be able to do things. So that's a good feeling.” Ivy

> “So, I think **AAU will provide me a good background for the future** with that, especially the project-based learning. I mean the reason why I'm here because nowhere else I saw that you can **actually work from something real** that can be produced in a company. I can say graduates with years of PBL experiences like these could **better prepare for their future jobs**.” Ken

4.3 Interests

Find the interest in problem-solving

In the interviews, two students reported they developed the interest in problem-solving via the PBL experience. As what Daisy said, it was an enjoyable process for her to figure out the rationale behind the problem and then apply her own understanding into practice to solve problems. Problems exist in every aspects of daily life, so the PBL experience provided her more training on solving problem.

> “For me, **problem solving makes engineering interesting for me**. The feeling I get when I solve a bigger, more difficult problem is really good. The feeling is like that I'm studying something, and then I click how it works. And I can apply it anywhere because I have understood how it works. I love that feeling, and that's a process of problem solving because everything is problem, and we're just doing problem solving with the project and everything.” Daisy

Enhance one's interest in engineering

Three students mentioned the enhance of their interest in engineering. Different from theoretical work, doing projects and developing new products had more connections with daily life. The processes of applying engineering knowledge in real life is new experience for those international engineering students, which inspired their interest in engineering. In Ivy's case, compared with traditional learning methods in her home university, she got more opportunities to work in a real-world engineering environment and to use various engineering equipment to make products for their projects.

> "It's very interesting because we **have the opportunity to work with real equipment** which is really cool so far. In my previous education, I haven't had the opportunity for that. And there are really a lot of opportunities here to take part into some extracurricular activities with your team members. I don't know maybe someone wants they can make their own start-up and stuff like that. So, I think that's **very helpful, making engineering more interesting**." Ivy

However, although evidence on the development of international students' interest in engineering were reported, students also reflected the challenge of heavy workload in PBL context, which might reduce the satisfaction level of their learning experience. One participant, Gina, had no PBL experiences in her bachelor study, and this was her first time to conduct an ill-structured project in a team. On one hand, she mentioned that PBL enhanced her interest in engineering and brought her better learning outcomes. On the other hand, as a "PBL beginner", it was challenging for her to adapt the PBL paradigm and the learning approach of teamwork. She needed to put in much effort and time to keep pace with the team, which made her feel doubtful about the balance of input and output. In the interview, she called for less workload in PBL and teamwork processes.

> "I think PBL enhances my interest in engineering because I think the **program here or the way they teach us** is so good. We learn much more then. I don't know others, but I learned much more than in my bachelors. And I think that I **have an idea what's going on in the semester** because in my bachelors, sometimes I didn't know what was going on. And then just before the exams, I just studied one week just preparing for the exam. So, now is much better, more interesting to learn new things. But one thing **which is not so interesting is the heavy workload**. Sometimes, it's so tiring, so much times that it takes, making our life hard. So, that makes me a bit, I don't want to say depressed, but sometimes I'm thinking about if it's worthy. Maybe less workload would be better." Gina

5 Discussion and Conclusion

Framed in the engineering identity model, this study explored how AAU PBL model contributed to the formation of engineering identity of international engineering students, who had no teamwork or PBL experiences before. Based on semi-structured interviews, students reported their engineering identity development via PBL experiences in AAU in the dimensions of performance, recognition and interests.

Performance: Compared with those international students' learning experiences in their home universities, one of the biggest benefits of AAU PBL model is the opportunity to link theories to practice, which could shorten the gap between universities and industries, in accordance with findings on local students. (Kolmos & Holgaard, 2019). Through working as real engineers in teams, students pointed out that they further understood the significance of transferable skills and reported the improvement of their teamwork skills, communication skills, problem-solving skills, emotion and time management skills.

Recognition: In this dimension, several students' self-confidence was found to be enhanced by recognitions from peers and supervisors. Recognitions from members in the professional communities can motivate individuals to develop the sense of belongings (Strayhorn, 2018). In engineering education, positive feedback and comments from engineering staff could inspire students' belief in their abilities to be competent to engineering work (Leydens et al., 2017). In addition, by experiencing AAU PBL model by themselves, those international students realized the benefits of PBL for future engineering jobs and got more self-confidence of preparation for their engineering career, which promotes their engineering identity and might enhance their persistence in engineering (Meyers et al., 2012).

Interests: PBL was pointed out as an effective method to enhance students' interests in engineering. For these international students without PBL experience, their first projects inspired their interest in problem-solving. In PBL, the opportunities to work with real engineering equipment aroused students' curiosity and made the learning processes more vivid. Learning by doing in PBL could support students' deep learning in professional knowledge, practical skills and engineering competences (Cobo-Benita et al., 2010), and participants in this study also reported better learning outcomes in AAU PBL model than in traditional learning.

Although AAU PBL model was identified by international students as an effective way to develop their engineering identity, challenges were also mentioned during the interviews. Previous studies have pointed out that culture differences brought difficulties for overseas students' learning experience in PBL (Du & Hansen, 2005). Especially, non-western students coming to western universities might face marginalization socially and academically (Selvarajah, 2006; Gram et al., 2013). In addition, transferring from traditional learning context and adapting those active learning methods challenges international students, specifically for students who come from environments where teachers are the center of learning and authorities of knowledge (Du et al., 2020). In this study, as entry-level PBL learners, several students also reported that it was a challenging job for them to adapt the PBL paradigm and overcome difficulties such as heavy workload, team pressure and self-doubt. More attentions are needed to focus on the challenges faced by PBL beginners. The PBL curriculum for international students could be optimized with more components of PBL skills trainings and pedagogical workshops.

In terms of limitations of this study, there were only six participants in the interviews, which might influence the richness of the collected data. However, this study serves as a polit study and provides primary findings of the contributions of AAU PBL model on international students' engineering identity. Future work will expand the sample size to make comparison between students' prior learning experience and PBL experience in AAU, and to explore the challenges they meet as "PBL beginners" in their teamwork processes. More attentions could be paid on the long-term influence of PBL on students' engineering identity development. With more finished projects, international students might have more learning experiences and reflections on the differences between traditional learning methods and the AAU PBL model.

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Fostering Creativity in Engineering through PBL

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Abstract

This work introduces a literature review analysis that focuses on contributions oriented to fostering creativity in engineering. The review analysis considers practices, scenarios, activities, and tools designed to promote creativity in students by using problems or projects as catalysts for creativity. As a result of this review, the authors identified some elements considered for the promotion of creativity in engineering such as originality, fluidity, flexibility, elaboration, divergent and convergent thinking, and others that should be fostered like tolerance of ambiguity and risk-taking. The study shows that there are different strategies, demonstrating that the research on the promotion of creativity is increasing. The authors classified the studied contributions in six groups according to the strategies incorporated in the encouraging activities, one of which considers interventions with projects. These interventions, in turn, were classified into two clusters taking into account the alignment of the elements included in a PBL intervention. Considering that creativity is crucial for engineering, and it is one of the skills that an engineering curriculum should instil in the professional, it is not clear yet, why is creativity not an explicit part of all engineering curricula? And Why is creativity overlooked in engineering education? These and other questions and their possible answers motivate the interest of studying the promotion of creativity. This work seeks to serve as an introduction document for someone who wants to incorporate elements of creativity into the curriculum design by using project approaches and aims to contribute to solving the stated questions.

Keywords: Creativity, engineering education, PBL, creative thinking, divergent thinking.

Type of contribution: PBL review / conceptual paper

1 Introduction

Considering the current challenges, the complexity, and diversity of 21st-century technologies that demand novel solutions for the contextual problems; creativity has become an indispensable quality for engineering and a skill that grows in importance. Usually, the concept of creativity includes, as a result, a novel and useful product, which is remarkable by its novelty, resolution, elaboration, or synthesis, and its design or production. Moreover, creativity and innovation are the basis for solving problems in engineering and determine ways how engineers obtain new solutions or products.

The promotion of creativity has been studied since the beginning of the 20th-century. Wallas (1926) describes the four stages of the creative process, namely, i) preparation, ii) incubation, iii) illumination, and iv) verification, defined from his empirical observations and stories of famous inventors. In the middle of the 20th-century, J. P. Guilford as president of the American Psychological Association (APA) promoted the investigation about the nature and assessment of creative thinking skills and proposed four stages for problem-solving, which he labelled as i) recognition, ii) production, iii) evaluation, and iv) drawing (Guilford, 1950, 1959). In the same way, Rhodes (1961) defined four aspects that influence creativity, called the Four Ps (Person, Product, Process, and Press or environment), describing their interrelation to produce the development of a creative result. Many years later, in (J. C. Kaufman & Beghetto, 2009), the authors developed a model of four categories of creativity that helps to expose the nuances between different levels and types of creativity. This model, called the Four-C, classifies a person according to her creativity who could fit into multiple categories relying on the area; the two most relevant categories are the little-C and mini-C creativity for schools, these categories deal with the individual growth achieved through small ideas, and Pro-C and Big-C for a professional level, which requires impact in the context.

Other contributions focus on strategies for promoting creativity, for example, Sternberg (2007) described twelve strategies that guide the development of the habit of creativity; Kazerounian & Foley (2007) proposed ten maxims of creativity; and D. Cropley (2015a, 2015b) presented aspects for integrating creativity in the curricula. These contributions show how the study of creativity has become an interesting research topic, describing diverse concepts, approaches, perspectives, and applications.

1.1 Defining Creativity

There is a close relationship between creativity and engineering. According to the U.S. Accreditation Board for Engineering and Technology, engineering is: “the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilise economically, the materials and forces of nature for the benefit of mankind” (ABET, 2011). From this definition, we can note that creativity is immersed in Engineering; in the same sense, Torrance (1963) defines creativity as “the process of detecting problems or gaps in information, forming hypothesis ideas, testing and modifying these hypotheses, and communicating the results.” Likewise, other researchers as (R. Sternberg & Lubart, 1999) define creativity as “the ability to produce something that is novel and useful.” Therefore, creativity can be understood as a combination of different skills, knowledge, motivations, and attitudes to face a challenge or solve a problem.

In most cases, definitions of creativity focus on the individual; however, all definitions of creativity imply a social context. One of the most complete definitions of creativity is proposed by (Plucker, Beghetto, & Dow, 2004), who stated: “Creativity is the interaction among aptitude, process, and the environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context.” Creativity is closely linked to the social conception of acceptance and validation, and consequently, societies directly influence the creativity of people, both in its conception and validation. Csikszentmihalyi (1999) calls this social influence as "social-cultural validation."

1.2 Creativity and Engineering

We observe that engineering lays stress on solving problems in a creative way that concern with daily and contextual needs and the development or use of new technologies. Where the terms 'creative way' relate to the generation of useful and novel solutions. In summary, as Cropley (2015a) states “creativity and engineering are, in essence, two sides of the same coin.” If solutions to new problems remain like past problems solutions, we are facing a stagnation of development. But, if, the obtained solution is new or novel, then we have 'a creative solution', which certainly will drive technology. This reflection highlights the importance of creativity promotion in engineering, beyond something evident in the training of engineers. Therefore, engineering education must foster creativity through the curricula to guarantee an education that engages engineers to generate new and useful solutions.

This document introduces a review of fostering creativity in engineering curricula and the use of Problem-Based Learning (PBL) or project approaches as an educational method to accomplish that. In other words, this review devotes to show aspects that allow researchers to know how creativity is being dealt with the engineering curricula design by using student-centred approaches that consider projects to drive the learning.

The rest of the paper is organised as follows: Section 2 lists some works that discuss creativity in engineering, which have been classified in six groups concerned to i) fostering activities, ii) maths and creativity, iii) creativity and other areas (e.g., arts and design), iv) creativity labs v) training and vi) use of problems and projects. Section 3 deepens on the research in creativity promotion in engineering and focuses on works that foster creativity through Problem and Project-Based Learning, or the execution of projects for solving contextual challenges that are not strictly considered a PBL application. Finally, the authors present some considerations to carry out future research intended to encourage creativity in engineering students that belong to traditional education programs or where PBL integration is minimal.

2 Creativity in Engineering Education

According to Belski (2017), Engineering Creativity is the ability to generate novel solution ideas for open-ended problems, ideas that appear not obvious to experts in a particular engineering discipline, and which can be considered by them as potentially useful. Engineering focuses on problem-solving and usually requires convergent and divergent thinking on the solution, two skills that are crucial in the promotion of creativity. In the problem solution, there is often a first stage associated with divergent thinking –to generate multiple responses– and a second one related to convergence thinking –to generate a correct answer– (Charyton, Jagacinski, & Merrill, 2008; Charyton & Merrill, 2009). The two kinds of thinking are essential features of the research on creativity in Engineering; many contributions deal about to find approaches, strategies or activities to encourage, enhance and nurture creativity, through classes or subject exercises, training programs, applications, projects or, including fusions with other areas. All of those have as the main goal that students strengthen their creativity and achieve the learning objectives. One of the main challenges is to provide students with a good understanding of creativity that allows them to develop tools to face new challenges.

Some research and proposals stress on the campus as scenario for the creativity, or on the curriculum design for fostering creativity; for example, in (Chen, Tao, & Zhou, 2018), authors propose the promotion of a creative culture at University campus for encouraging creative engineers across a friendly environment. This proposal aligns with the Four-Ps model of Rhodes, especially with that called Press. Likewise, in (Chia & Cho, 2018), authors carry out a study about the effect of a design-based curriculum, where the students have an active role in managing their learning, authors analyse how this strategy helps to foster creativity and entrepreneurship. In the same way, Lim, Lee, & Lee (2014) propose a theoretical framework for a curriculum that promotes creativity; authors consider that the development of creativity cannot only depend on sporadic teaching of creative thinking techniques or their participation in furtherance environments. In research, they present that creativity should be fostered throughout the curriculum and propose a set of courses organised to accomplish it.

Taking into account that in engineering education, the research on creativity promotion focuses on encouraging students in creative thinking, and considering different points of view to those that they commonly have, we classify the studied contributions in groups. The groups were defined regarding how the strategy implemented or designed was incorporated into the program training or course and the research focus. Thus, we found that in engineering education the most of works related to fostering creativity can be classified in one of these six groups:

i) Complementary activities to training through scientific creativity, collaborative work, or inclusion of elements of creativity, where research activities in the classroom are encouraged to enhance creativity and knowledge in a specific area, (Astutik & Prahani, 2018; DeHaan, 2009; Kozlov & Shemshurina, 2018);

ii) Mathematics and creativity strategies: these encourage creative thinking to solve mathematical problems. (Catarino, Nascimento, Morais, Campos, & Vasco, 2019; Katz-Buonincontro, Hass, & Friedman, 2017);

iii) Disruptive activities, creativity and other areas (e.g., arts and design), which combine art and other disciplines to promote creativity in a specific field; for example, using principles of the arts or theatre in engineering design, (Aguilera, 2017; Allen & Heaton, 2018; Hautala & Ibert, 2018);

iv) Laboratory activities, which seek to strengthen the concepts of science and engineering. (Domin, 2008; Russell & Weaver, 2011);

v) Courses in creativity or training during different sessions throughout a semester, enhancing in students the comprehension of creative concepts. (Bourgeois-Bougrine, Buisine, Vandendriessche, Glaveanu, & Lubart, 2017; Feijoo, Crujeiras, & Moreira, 2018; Morin, Robert, & Gabora, 2018);

vi) Use of problems and projects for fostering individual and group creativity. The activities are integrated to allow collaborative, interdisciplinary, intercultural, and also lead participants to divergent thinking to solve problems. (Satolo, Maestrelli, Ximenes-Satolo, & Ferraco, 2015; Treffinger & Isaksen, 2005; Valentine, Belski, Hamilton, & Adams, 2019; Zhou, 2015; Zhou, Kolmos, & Nielsen, 2012).

It is important to clarify that the same work can be classified into two different groups because it integrates characteristics common of both groups. For example, Zhou (2012) integrates collective creativity and PBL; and Dumas, Schmidt, & Alexander (2016) integrate the assessment of three cognitive abilities and TRIZ ideation method (problem-solution). This classification shows the importance of promoting creativity and different ways.

3 Project or Problem and PBL used to foster creativity

This section discusses approaches for fostering creativity through Problem and Project-Based Learning, or the execution of projects for solving contextual challenges that are not strictly considered a PBL application. These approaches correspond to the contributions classified in the group vi) in Section 2. The contributions were classified into two clusters. Cluster 1 corresponds to PBL contributions, and Cluster 2 relates to other contributions that consider projects.

The contributions grouped in Cluster 1 propose PBL interventions to motivate the group and individual creativity in engineering education along with other skills. As it is known, PBL works as an active learning scheme in a classroom to meet the challenges of professional performance, which depends greatly on design and creativity (Qattawi, Alafaghani, Ablat, & Jaman, 2019). PBL models share some characteristics like curriculum structure, the learning process, and assessment (de Graaff & Kolmos, 2003). Among elements considered in the 'PBL alignment model' proposed by Kolmos, de Graaff, & Du (2009) are i) objectives and knowledge; ii) types of problems, projects, and lectures; iii) progression, size, and duration; iv) student learning; v) academic staff and facilitation; vi) spaces and organisation; vii) and evaluation and organisation. All works classified in this cluster incorporate the elements of the PBL aligned model.

In the literature review analysis, the authors observed that most approaches consider commonly six factors of those proposed in the Reisman Diagnostic Creativity Assessment (Reisman, Keiser, & Otti, 2016). These factors are: i) originality, ii) fluency, iii) flexibility, iv) elaboration, v) divergent thinking, and vi) convergent thinking, neglecting others like the tolerance of ambiguity, resistance to premature closure, risk-taking, intrinsic motivation, and extrinsic motivation. Table 1 shows the main characteristics of the reviewed contributions grouped in Cluster 1. Some characteristics in those researches are the use of diverse strategies to encourage creativity in the curriculum such as: To i) integrate creativity training into the curriculum, ii) introduce real-life engineering projects, and iii) evaluate skills, including creativity. The studied researches assess how engineering students perceive these strategies and how they get benefits to improve their project work skills, concepts of creativity, and confidence for being creative.

Table 1: Remarkable characteristics in some Research about PBL (Cluster 1).

Reference	Characteristic										
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
(Zhou, Holgaard, Kolmos, & Nielsen, 2010)					X						C/W
(Volpentesta et al., 2012)					X	X					C
(Zhou et al., 2012)					X						C/W
(Zhou, 2015)					X						C
(Hu, Li, & Chen, 2015)					X	X					C
(Rodríguez et al., 2015)					X						C

Characteristics: C1: Originality, C2: Fluency, C3: Flexibility, C4, Elaboration, C5: Divergent Thinking, C6: Convergent Thinking, C7: Tolerance of ambiguity, C8: Resistance to premature closure, C9: Risk Taking, C10: Intrinsic and Extrinsic Motivation, C11. Creativity is foster in course or workshop.

The contributions classified in Cluster 2 show strategies to strengthen the creativity through the solution of problems or execution of projects, enhancing different skills. In this case, the project or problem is formulated to foster creativity; without being strictly a PBL approach –these approaches do not meet with all elements considered in a PBL alignment model (Kolmos, De Graaff, & Du, 2009). In this cluster, we can find contributions that explore other methods or approaches. One of the most remarkable is the TRIZ method (*Tieoriya Riesheniya Izobrietatielskij Zadach*, in Russian), which is known in English as Theory to Solve Problems of Inventiveness. This method, developed by Genrich Altshuller and his colleagues in 1946 (Altshuller, 2002), is a systematic method that seeks to use creativity for solving a problem. The method starts from a specific problem, leads to a more general abstract problem to generate an abstract solution and, finally, to obtain a particularly creative solution.

Table 2: Remarkable characteristics in some Research about Projects or Problem-solving (Cluster 2).

Reference	Characteristic										
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
(Johari et al., 2011)					X	X					C
(Chung et al., 2012)					X						C
(Cropley, 2015a)					X	X					C
(Dumas, Schmidt, & Alexander, 2016)	X	X			X						C
(Starkey, Toh, & Miller, 2016)	X	X	X	X	X	X					C
(Valentine, Belski, & Hamilton, 2017)	X				X						C
(Bourgeois-Bougrine et al., 2017)	X	X	X	X	X						C
(Santos, Martins, Brito, & Ciampi, 2019)	X	X	X	X	X	X			X		C

Characteristics: C1: Originality, C2: Fluency, C3: Flexibility, C4, Elaboration, C5: Divergent Thinking, C6: Convergent Thinking, C7: Tolerance of ambiguity, C8: Resistance to premature closure, C9: Risk Taking, C10: Intrinsic and Extrinsic Motivation, C11: Creativity is foster in course or workshop.

Table 2 shows the main characteristics of contributions grouped in Cluster 2. These works present the design of a single course to foster creativity for engineering students that links include the teaching and learning activities, curriculum objectives, and assessment tasks. The different authors show the advantages of developing the encourage creativity. Moreover, for example, Chung, Lou, Chao, Tseng, & Shih (2012) considers the project assessment by a panel of experts through a questionnaire. And Bourgeois-Bougrine et al. (2017) introduced 13 creativity and development tools to students along the course, focusing on the effectiveness of these tools during a conceptual product design challenge.

Tables 1 and Table 2 show the main characteristics of reviewed contributions from researches on creativity promotion. In the analysis, we observed that all contributions integrate collaborative, interdisciplinary, and intercultural work, and lead participants to encourage divergent thinking. The consulted authors use mainly PBL, and TRIZ approaches to promote creativity crosswise along with other skills or abilities, through the strengthening of divergent and convergent thinking. It is observed that the main characteristic that is promoted is the idea generation (divergent thinking), for example, through the number of novel ideas in relation to the assigned challenge. Regardless of the chosen approach, all contributions intend to nurture seven elements: the i) group learning, ii) problem solving, iii) project management, iv) facilitation, v) enhancement of the environment, vi) generation, and exploration of new ideas, and vii) autonomy. The alignment of these elements becomes the main challenge for offering an appropriate learning environment to develop creativity.

3.1 Assessing Creativity

The researches presented in Table 1 and Table 2 usually consider the assessment of creativity through questionnaires and rubrics and panel of experts (who belongs to the disciplinary area and are not necessarily experts in creativity). For assessing, researchers use commonly: reports, workshops, results of the project or problem solution, or other data from students' feedback. The assessment typically considers learning outcomes and some skills or competencies, including creativity as information sources. Although many aspects related to creativity are part of the diagnosis, usually, the researchers do not use an instrument to test this skill, and commonly the panel of reviewers is not exclusive for this topic. Such suggests the assessment prioritises the disciplinary knowledge and skills related to the career, taking creativity as an integrated ability. This consideration could produce imprecisions in measuring creativity. In addition, most of the contributions are centred on the evaluation concerning the promotion of creativity during the development of a course or workshop, lacking subsequent assessments in the medium and long term. Therefore, it would be recommendable to use specific creativity evaluation tests and expert reviewers on the topic to have a better diagnosis of the creativity nurturing process.

3.2 Curriculum and Creativity

Even though engineering projects demand creative and innovative approaches to produce new and useful ideas and projects, it is essential to understand that traditional engineering curricula does not enhance the creative capabilities of students significantly, since these centre on teaching more than learning. Some of the studied works recommend that the engineering curriculum should incorporate activities focus to foster creativity among engineering students, (Cropley & Kaufman, 2019; Ibn-e-Hassan, Abu Talib, Riaz, & Iqbal, 2014; Tan, 2003). To achieve an adequate promotion of creativity, culturally specific and historically contextualised approaches are needed (Glaveanu, 2018).

The creativity research community has provided the theoretical and understanding blocks that characterise a creative person. Therefore, it is necessary to fostering and nurturing creativity and elements that promote it. We recognise widely that this transformation is not always easy and that teachers often only have a vague idea of what creativity is and how to foster it. In the light of these problems and the analysis of the available evidence on creativity, we find it necessary to look for 'a model that promotes creativity in any engineering curriculum,' a student-centred model. A model that interlock projects, technology, technical knowledge, methodologies of the creative process, and creativity assessment, in a learning scenario that guarantees the solution of contextual problems with a global view.

4 Concluding Remarks

This work stresses on looking for the interrelationship between fostering creativity and engineering education, and trends or opportunities for encouraging creativity. As a result of the literature review, researchers observed that:

The fostering of creativity is being assumed as an essential aspect of the training of the engineer, generally through projects or other alternatives, such as the TRIZ method. Likewise, it was possible to find different research areas that deal with creativity promotion in higher education and observe how one of the most used strategies for promoting creativity is the solution of problems and execution of projects. In the manuscripts consulted, the use of projects is formulated as a formal PBL approach, or as academic or evaluation activities that are not strictly tied to a PBL model.

Research on the promotion of creativity in engineering is continuous growing; the review showed that universities around the world are assuming the challenge of promoting creativity. Most of the contributions consulted show multiple methods and approaches focused on strengthening some factors associated with creativity like originality, fluency, flexibility, elaboration, and divergent and convergent thinking.

All considered papers include the promotion of creativity in engineering curricula as a primordial need in engineering education that goes beyond than just mentioning it in the syllabus. It is essential that future engineers think creatively considering the challenges they will have in their professional life. Creativity will be responsible for innovations and new developments in engineering. Thus, fostering creativity has become a significant challenge in the curriculum design.

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Teachers role in PBL

The Jigsaw Classroom: A Student- Centered Learning approach applied in Training of Trainers in Africa

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Abstract

Universities in Africa face challenges such as, textbook-based curricula and obsolete pedagogical methods. The Erasmus+ funded project *Enhancing Entrepreneurship, Innovation and Sustainability in Higher Education in Africa* aims to address such challenges by ensuring curricula that are relevant to social and economic needs of Africa and are delivered through student-centred learning approaches, including problem based learning. Such curricula will serve as “best practice” examples within the African partner universities and may contribute to sustained educational change in higher education in Africa.

The first part of the project was Training of Trainers, i.e. training of the teachers in the African partner universities to redesign study programmes in accordance with project aims. This paper presents the conceptual considerations in relation to the planning of the Training of Trainers that was organized as a modified version of the Jigsaw Classroom.

Keywords: Higher education in Africa, Training of Trainers, Student-centred learning, cooperative learning, Jigsaw Classroom.

Type of contribution: PBL concept paper

1 Introduction

In connection with the Erasmus+ funded project *Enhancing Entrepreneurship, Innovation and Sustainability in Higher Education in Africa* (EEISHEA), presented in detail in section 2, a first project activity was Training of Trainers. This training focused on equipping the teachers in the five African partner universities with necessary knowledge, skills and competences in the four cross-cutting areas of sustainability, entrepreneurship and innovation, student-centred learning and e-learning, to redesign chosen study programmes in accordance with project aims. The training was organized according to a modified version of the Jigsaw Classroom, a student-centred cooperative learning approach that enhances commitment and collaboration of students. This paper describes the conceptual development of the framework for the Training of Trainers.

The second section of the paper presents the EEISHEA project, including the underlying rationale for developing the framework for the Training of Trainers. The third section is a short literature review of the Jigsaw Classroom approach, describing the original approach as well as later variations. In the fourth section, the EEISHEA Training of Trainers, organised as a modified version of the Jigsaw Classroom approach, is presented. The last section contains a discussion and recommendation for future application of the Jigsaw Classroom approach to student-centred learning in African higher education.

2 The EEISHEA project

This section describes the case study that provided the opportunity to experiment with Training of Trainers. In the first subsection, the project itself, with project partners, aims, activities and outputs is described. The second subsection describes the training and the rationale for looking for a modified structure for the training.

2.1 The project

The EEISHEA project is funded by Erasmus+ under the programme 'Capacity Building for Higher Education'. Project *partners* are five European universities and five African universities, located in Tanzania and Ghana. Please see Appendix 1 for the list of partner universities. The main *aims* of the project are to address some of the challenges faced by universities in Africa, such as, weak links to the socio-economic context, textbook-based curricula that do not address local socio-economic problems and obsolete pedagogical methods of delivery.

The main *output* of the project will be five 'best practice' curricula with integrated elements of sustainability, entrepreneurship and innovation, and delivered through student-centred learning approaches, including problem based learning, while applying available e-learning tools. These curricula will serve as "best practice" examples within the African partner universities. Each African university has chosen a highly relevant study programme that will be (re-)designed through a curriculum development process. Please see Appendix 1 for the list of study programmes. Preparation for this curriculum development process is the training of the African university teachers; thus, the two main *activities* in the project are Training of Trainers (ToT) and curriculum development.

In each of the five African universities, an EEISHEA Local Task Force (LTF), consisting of 10 – 12 persons, has been established. These LTFs have been assigned the task of jointly redesigning the chosen curriculum, i.e. they have to integrate relevant elements of Sustainability (SUS) and Entrepreneurship & Innovation (E&I) into the curriculum contents, while applying Student-Centred Learning (SCL) approaches, as well as available E-Learning (E-L) tools in the delivery of the redesigned curriculum.

2.2 The Training of Trainers

The first part of the EEISHEA project was the ToT, i.e. training focused on equipping teachers in the African partner universities with knowledge, skills and competences to develop curricula in accordance with project aims. This ToT was organized according to a modified version of the Jigsaw Classroom, an approach to student-centred learning that to the knowledge of the authors has not previously been widely used in Higher Education in Africa.

The rationale for looking for a modified approach to ToT is to be found in the project that was the predecessor for the EEISHEA project, i.e. the Building Stronger Universities (BSU) E-Learning and Problem Based Learning (PBL) project, funded by Danida and lasting from 2013 to 2016. Four of the five African universities and the three Danish universities involved in EEISHEA, were partners in the BSU project. This project also included ToT that was organized in a traditional way, with face-to-face training workshops facilitated by two Danish trainers in Africa, 3 workshops in Tanzania and 3 in Ghana over a period of 6 months.

Evaluation of this ToT showed that, although positive results were reported in terms of introduction of PBL and e-learning at course level in some courses, the level of commitment and the level of collaboration in the local teams was not as high as might be expected. This might have been partly caused by the well-known fact that, when workshops are conducted in a partner university, the participants from the host institution often experience unavoidable disturbances from administration, colleagues or students during the workshop. Another element seemed to be that the local teams were not 'closely knit', i.e. not the same people from the African universities participated from workshop to workshop, making it difficult to conduct a progressive training programme. In the EEISHEA project, the intention was to effectuate educational change at programme level and therefore there was a felt need to strengthen *commitment* and *collaboration* in the LTF and in the ToT. The Jigsaw Classroom was identified as a pedagogical approach that might enhance these two characteristics. The following section presents a literature review of the Jigsaw Classroom, the original approach, as well as later variations.

3 The Jigsaw Classroom explored

This section reviews the literature on the Jigsaw Classroom (JSC), which is the focus of this paper. In the first subsection is presented the basic principles of cooperative learning, an umbrella term for a number of small-group learning situations, including problem-based learning and JSC. The second subsection presents the history and the original version of the JSC, while the third subsection presents variations of the original JSC developed for specific purposes. In the final subsection, the findings from the literature review are summarised, with focus on use in the EEISHEA ToT.

3.1 Basic principles of cooperative learning

Cooperative learning is an educational approach that has met with great success over the past 50 years (Johnson and Johnson, 2009). According to some researchers, cooperative and collaborative learning are two different approaches to active, student-centred learning in small groups (Matthews et. al., 1995; Bruffee, 1995), while other researchers see cooperative learning as a subset of collaborative learning (Felder and Brent, 2006). In educational discourse, the two terms are often used interchangeably, and indeed both are based on John Dewey's understanding of learning as an active and social process of acquiring knowledge. Focus in this subsection is on cooperative learning, since the Jigsaw Classroom is a variation of cooperative learning.

The five basic principles underlying cooperative learning are the following (Felder and Brent, 2006; Dave, 2017):

- Positive interdependence, i.e. all students in the small group are dependent on each other and rely on each other's contributions to achieve the desired group product and the intended learning outcomes
- Individual accountability, i.e. each student in the group is accountable for the complete group product and must be able to master all knowledge that the group has accumulated, including what other group members have contributed
- Promotive interaction, i.e. students help each other to perform their learning tasks through feedback and encouragement
- Interpersonal communication, i.e. students practice negotiation, decision-making and conflict management, and they learn through expressing opinions and active listening to everyone's viewpoints,

- Reflective self-evaluation, i.e. students in the small group regularly reflect on and evaluate their performance as a team, to identify helpful as well as harmful actions, with the aim of improving group performance in future.

The above principles for cooperative learning may be implemented in different ways, and therefore a diversity of teaching and learning approaches fall under the umbrella of cooperative learning, including problem-based learning and JSC (Johnson and Johnson, 2009).

Some of the major benefits of cooperative learning reported in literature are higher self-esteem and better social skills (Dave, 2017), increased motivation, persistence working towards a joint goal, higher satisfaction and increased commitment towards the task at hand (Johnson and Johnson, 2006; Slavin, 2011). Although most examples of cooperative learning reported are from a western context, there is no evidence that benefits of cooperative learning should be culturally dependent; rather they are context-dependent (Tran and Lewis, 2012).

The next subsection presents the original Jigsaw Classroom approach to teaching and learning.

3.2 The original Jigsaw Classroom

The Jigsaw Classroom is a form of highly structured cooperative learning designed by Professor Elliot Aronson and his graduate students of education in Austin, Texas, in 1971. Aronson's own recall of the situation is as follows:

> *We invented jigsaw as a matter of absolute necessity to help defuse a highly explosive situation. The city's schools had recently been desegregated and, because Austin had always been residentially segregated, white youngsters, African American youngsters, and Hispanic youngsters found themselves in the same classrooms for the first time in their lives. Within a few weeks, longstanding suspicion, fear, distrust, and antipathy between groups produced an atmosphere of turmoil and hostility, exploding into interethnic fistfights in corridors and schoolyards across the city. …… After observing what was going on in classrooms for a few days, we concluded that intergroup hostility was being exacerbated by the competitive environment of the classroom. In every single classroom, the students worked individually and competed against each other for grades.* (Aronson, 2002, 216).

In the Jigsaw Classroom, students participate in two small groups: The Jigsaw Group or Home Group and the Expert Group. The original Jigsaw process may be summarized in four basic steps: 1) The students (normally between 4 and 6) are divided into Home Groups (HG) that have to do a joint assignment. The assignment material is divided into segments, one segment for each member of the HG. The students have access only to their particular segment of the assignment material. 2) Each student is given time to study her segment on her own. 3) Students with similar segments gather in the Expert Group (EG) to discuss the contents of their common segment and to discuss how to present the segment to the HG. 4) Students return to their HG and take turns presenting their segment of the joint assignment to the other members of the HG.

To these 4 steps may be added various process evaluation and/or assessment steps, individually or in groups. In the original JSC, an individual test, for example in the form of a quiz, is administered to the students at the end of the class. This test covers all segments of the group assignment and therefore, students need to pay attention to and learn from each other's contributions.

The name 'Jigsaw' refers to the fact that - just as in a jigsaw - each segment of the given joint assignment is necessary to create the full picture. This means that each student's contribution is needed for the HG to be able to fulfil their joint assignment and for each student to pass the test (Aronson and Bridgeman, 1979). Figure 1 is an attempt to illustrate the process.

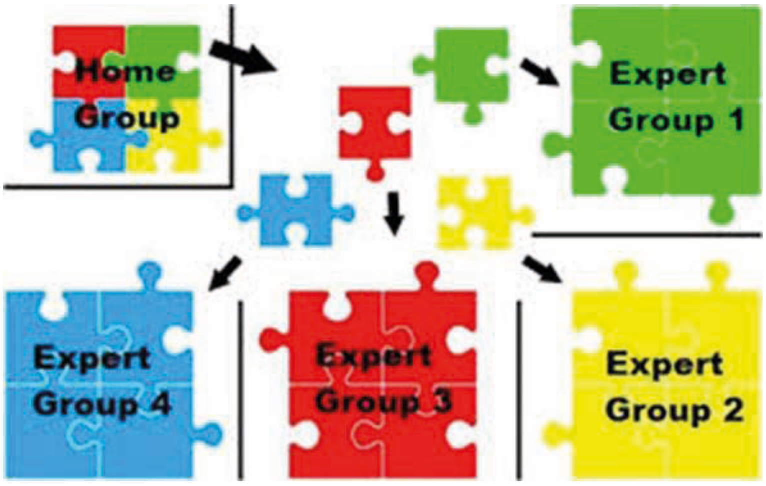

Figure 1. The Jigsaw Classroom illustrated (https://strategiesforspecialinterventions.weebly.com/jigsaw1.html#)

From the description of the JSC, it is obvious that the first four of the five principles of cooperative learning are implemented, while the last principle of reflective self-evaluation is not an integrated part of the original JSC; this is, however, found in some of the variations that will be described in the next subsection.

Research on the effects of the original JSC has documented that students in the JSC classroom demonstrated greater liking of peers, both within and across ethnic boundaries, their self-esteem increased and they liked school better than before the JSC was introduced (Blaney et. al., 1977; Cook, 1985; Walker and Crogan, 1998). Also, their degree of empathy increased (Bridgeman, 1981), as did their engagement and intrinsic motivation (Perkins and Tagler, 2011).

One study of academic performance in the JSC showed that in inter-racial classrooms, minority students performed considerably better than in traditional classrooms, while white majority students' performance was unchanged (Lucker et. al., 1976). Another study found significant improvement in academic performance of the JSC students compared to control classes (Walker and Crogan, 1998). Furthermore, students understood the material better in the JSC than in the control classroom (Perkins and Saris, 2001).

A qualitative study documented that 40 final-year students of mathematics in a university in Vietnam who participated in a JSC class, appreciated working with others and getting help from peers, discussing and sharing information and carrying out peer teaching (Tran and Lewis, 2012). Increased self-efficacy and higher quality school experience among a group of vocational training students in a JSC in France was reported in Darnon et. al. (2012). A study in a US university found that students of cognitive psychology, who participated in an experiment applying JSC approach, reported increased ability to teach psychological concepts to others, increased ability to communicate and increased belief in themselves as scholars (Crone and Portillo, 2013).

A study among 5th graders focusing on attitudes towards self, peers and school and on attendance and achievement, found no positive effects in the JSC classes as compared to the control classes. Researchers attributed this to the reward structure in the original JSC:

> *However, unlike most other cooperative learning techniques, with Jigsaw there is no group product, nor do students receive grades based upon their group test performance. In the Jigsaw classroom, like the traditional classroom, the reward structure is individualistic or competitive.* (Moskowitz et. al., 1985, 111),

The researchers proposed to modify the original JSC to include some kind of group based reward structure, a proposal that has been followed up in later variations of the JSC.

Since the first implementation in the 1970s, the Jigsaw Classroom approach to cooperative learning has gained a number of followers, and different variations of the original method have been developed. In the following subsection some of these variations are described, including research results where available.

3.3 Jigsaw Classroom variations

The Jigsaw II approach designed by Slavin (1987) is quite similar to the original Jigsaw I, except that the test results from the individual test at the end of class are averaged to a group score and the group with the best score is rewarded. This competitive element is the main point in JSC II and the group score meets the critique mentioned above (Slavin, 1987; Moskowitch et. al., 1985).

The Jigsaw III approach was designed by Stahl (1994) to address and increase interaction between students in bilingual classes. This approach is very similar to Jigsaw II, except that at the end of class a whole group review process is added (Holliday, 2000). This approach was applied in a Turkish study of grade 6 children being taught written expression. The study found that children in the JSC group did significantly better than children in the control group in terms of academic achievement. Furthermore, they liked the JSC approach (Sahin, 2011).

Jigsaw IV, designed by Holliday (2000) was designed to meet students' concerns with the Jigsaw II approach. Examples of such concerns were: 'Free riders' and unequal distribution of work load among students; uncertainty about the (in-)accuracy of information conveyed by peers. The approach is in most respects similar to II and III but quizzes are added during the process, one quiz checking on accuracy of information discussed in expert groups and a second quiz checking on understanding of the material shared in the home groups. Based on quiz and test results, the teacher gives additional clarification on areas not well understood (Holliday, 2000).

The Reverse Jigsaw approach is called so because the aim of the approach is to facilitate the teacher's understanding of participants' perception of the material to be covered, whereas the aim of the original Jigsaw is to facilitate students' understanding of the teacher's material (Hedeen, 2003). The Reverse Jigsaw uses small-group discussions like other Jigsaw approaches but the process contains only 3 steps: 1) Students gather in *mixed* groups (3 – 5 students per group) and each student in the group facilitates a discussion on a specific topic assigned to her. 2) Students with similar topics gather in *topic* groups and share the main points of the discussion from their mixed group, in order to summarize the topic discussions from the mixed groups. 3) The whole class reconvenes and topic reporters present the summary from their particular topic group to the whole class. At the end of class the teacher may facilitate an evaluation of the Jigsaw process (Hedeen, 2003). The Reverse Jigsaw has been applied in adult training and the responsibility for learning is shared by the students, individually and in the classroom. As such, this is an example of an educational approach that can be

> *"liberating and empowering…when the classroom structure moves away from the banking system of education toward one in which students are encouraged to contribute their own voices and experiences"* (Hedeen, 2003, 329)

The latest variation of the Jigsaw classroom called Subject Jigsaw (Sahin, 2011) was applied in a group of 108 university students, learning about one-component phase-diagrams in General Chemistry. Students were divided into two classes, one experimental Jigsaw class and one control class. Students in the Jigsaw class were working in small groups: phase groups, transition groups and a triple-point group, the formation of which was closely related to the subject taught, therefore the name Subject Jigsaw (Doymus, 2007).

Results of the study documented a significant positive effect on the learning of phase diagrams, with students from the experimental group scoring significantly higher in a Chemistry Achievement Test than students from the control group (Doymus, 2007).

Following this description of variations of the Jigsaw Classroom, in the last subsection the most important characteristics extracted from the literature review are summarised, to form the conceptual framework for the EEISHEA ToT.

3.4 The JSC approach summarised

The large majority of studies on the JSC approach to teaching and learning documents a positive effect, at the personal level and/or at the interpersonal level.

Summarizing JSC effects at the personal level, we may distinguish between effects in the affective domain and effects in the cognitive domain. In the affective domain, increases in the following personal characteristics have been reported: Self-esteem, self-efficacy, self-confidence; motivation; engagement and commitment. In the cognitive domain, increases in academic achievement and in professional understanding are reported. Concerning the interpersonal level, improvements in collaboration, in the small groups as well as in the whole classes, have been reported, as have increases in empathy, intra- and inter-ethnic peer liking and peer teaching and –learning.

As mentioned above, the intention of structuring the ToT in an alternative way was to achieve increased commitment to the joint task at hand in the LTF, i.e. the curriculum redesign activities, as well as to improve collaboration, not only in the Local Task Force teams but also between teams across institutions. Therefore, focus was on these two characteristics: Commitment and collaboration, and in the next section is described how in the EEISHEA ToT the two characteristics were achieved.

4 The EEISHEA ToT approach

This section describes the EEISHEA ToT approach, including organisation, phases, location and main modifications relative to the original JSC.

The work in the ToT was *organised* as facilitated group work. The Home Groups (HG) were the Local Task Force teams with the joint assignment of curriculum development, while the Expert Groups (EG) were the four Training Teams (TT), consisting of two to three European trainers and 10 African trainees, two from each African partner university. Four EG/TT were established, one for each of the four cross-cutting areas: Sustainability (SUS), Entrepreneurship & Innovation (E&I), Student-Centred Leaning (SCL) and E-Learning (E- L).

Thus, each trainee in the ToT participated in two small groups like in the original JSC. Instead of appointing only one person, each African LTF appointed 2 trainees to each EG/TT. This was done to secure that there would be at least one trainee from each African partner university in either of the 2 European workshops.

Furthermore, the ToT was *organized* as blended learning, i.e. three face-to-face (F2F) workshops, supplemented by online learning. The F2F learning sessions took place as two training workshops, organized by the TTs and *located* in two different EU universities, and one training workshop, organized by the LTF and *located* in each of the five African partner universities. The complete training within each of the four cross-cutting areas had 6 *phases* as follows:

- Phase 1: Preparation phase – online material for preparation
- Phase 2: The first F2F workshop in the EG, located in EU institution 1
- Phase 3: Online learning and consultancy
- Phase 4: The second F2F workshop in the EG, located in EU institution 2
- Phase 5: Online learning and consultancy
- Phase 6: The third F2F workshop in the HG, located in each African university – focus on peer teaching and –learning.

The first eight F2F workshops in European universities were completed within a period of 3 months, from early December 2018 to early March 2019, while the five third F2F workshops in African universities took place during April – May 2019. Thus, the complete duration of the ToT was slightly longer than 5 months.

The six main modifications to the above described JSC variations were the following:

- Blended learning instead of direct F2F interaction
- Two trainees per HG/LTF in each EG/TT instead of one
- Two F2F workshops instead of one in the EG/TTs, both located in EU institutions
- EU trainers actively facilitating learning in the EG/TT through applied SCL, including a mix of short lectures, hands-on assignments, discussions and study visits, in the two F2F EU workshops
- Two trainees per cross-cutting area jointly responsible for and collaborating in the peer teaching of their colleagues in the HG/LTF in the third F2F workshops
- So far, no tests, evaluation or assessment of the trainees' learning has been conducted – the ultimate test will be the success of the redesigned curricula.

The location in an EU institution of the first two European F2F workshops was a deliberate choice to avoid the disturbances experienced in the BSU project and mentioned above. A perspective in using the Jigsaw Classroom approach in the ToT was that the teachers within the African universities would be able to use the same approach to organize student-centred learning in their own classrooms.

The ToT training was evaluated on an ongoing basis, by having trainees write Individual Reflective Learning Journals after each of the two EU workshops, and the five African universities writing Reflection and Evaluation Reports (RER) by the end of the completed training.

After the description of the ToT in the EEISHEA project, the last section presents a short discussion and recommendation.

5 Discussion and recommendation

In this section, the three authors discuss the usefulness of the modified JSC as structure for the EEISHEA ToT, based on observed project results to date. An in-depth research study of the effectiveness of the modified JSC in the EEISHEA ToT has been carried out and will be reported in a forthcoming publication.

5.1 Discussion

Initially, neither EU trainers nor African trainees seemed to be very familiar with the JSC approach to training and it took some explanation before the intention with and the structure of the modified JSC approach was well understood and appreciated by all project partners. An indication that the approach had eventually been understood, may be found in the peer teaching sessions in each of the third F2F workshops in the African universities. In these workshops an EU support team was present, in case assistance with the peer teaching in any of the four cross-cutting areas would be needed, but no such assistance were sought from any of the peer-teaching teams.

Another indication that the modified JSC approach achieved intended commitment and collaboration is that draft Programme Qualification Profiles (PQP) of the five redesigned draft curricula clearly demonstrate integration of qualifications within the four cross-cutting areas; thus documenting that the LTF has indeed collaborated to produce these PQPs, although the curriculum redesign processes have been delayed by the COVID 19 pandemic.

Furthermore, increased South – South (S-S) collaboration has been initiated, as has collaboration between southern and northern partners. Initially, this international collaboration was established during the ToT F2F workshops in EU, where participants had time to network and exchange teaching and research experiences, and it has been followed up during other project meetings and activities. The S-S collaboration, in areas such as innovation and aquaculture, was well underway when temporarily stopped by the COVID 19 pandemic, but is likely to pick up again when borders are opened.

5.2 Recommendation

Although detailed studies on the JSC approach are required to evaluate performance in African settings, the initial observations in the EEISHEA project gives positive indications that it can be effectively used in African higher learning institutions, particularly in Tanzania and Ghana. However, despite the positive observations in the EEISHEA ToT, it should be noted that the JSC method is still novel in the educational systems of the African countries and requires frequent in-depth theoretical and practical experimentation and appraisal.

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Appendix 1. List of EEISHEA project partners and redesigned study programmes

Partner no.	Partner name and acronym	Town	Country	Study programme
1	Aalborg University, AAU	Aalborg	Denmark	
2	University of Copenhagen, UCPH	Copenhagen	Denmark	
3	Roskilde University, RUC	Roskilde	Denmark	
4	Royal Institute of Technology, KTH	Stockholm	Sweden	
5	Universitat Politècnica de Catalunya, UPC	Barcelona	Spain	
6	Kwame Nkrumah University of Science and Technology, KNUST	Kumasi	Ghana	BSc Aquaculture and Water Resources Management (BSc AWRM)
7	University of Energy and Natural Resources, UENR	Sunyani	Ghana	BSc Renewable Energy Engineering (BSc REE)
8	Sokoine University of Agriculture, SUA	Morogoro	Tanzania	BSc Information Technology Innovation (BSc ITIN)
9	Kilimanjaro Christian Medical University College, KCMUCo	Moshi	Tanzania	MSc Monitoring and Evaluation of Health Programmes (MSc MEHP)
10	State University of Zanzibar, SUZA	Zanzibar	Tanzania	BSc Environmental Health (BSc EH)

The role of the teacher in a PBL teaching process

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Abstract

The purpose of this article is to address the role of the teachers when teaching the technology subject at the Danish higher examination programme (htx). It is also the intention to address how that role is expressed in practice where use of Problem-based learning (PBL) or some PBL principles is acknowledged as a strong teaching method. Further, it is our intention to discuss the teacher role in relation to readiness of the students evolving from first to third year in the programme. This will be seen in relation to; the development of the students PBL understanding, the cognitive readiness of the students and classroom dynamics.

Researching the role of the teachers in the technology subject at htx we observed in two different classes, in two different schools during a project period and discussed our findings with the teachers. In relation to the role of the teachers, we identified a variety of tasks the teachers have to deal with on a daily basis when teaching this subject. It places the teachers in a role where a very hybrid skill set is required which is a combination of technical and non-technical skills. Further, we have also found that the teacher's role and the teacher's tasks change as the students develop their skill set during the first year until the end of the third year from a more teacher directed role to a more student-centred facilitator role.

Keywords: Teachers' role, Problem-based learning, student readiness, hybrid skill set, Danish higher technical examination programme (htx)

Type of contribution: PBL research

1 Introduction

Established in the 1980s, the purpose with the Danish higher technical examination programme (htx) was to have a high school education stream specifically directed towards science and engineering (Danish Education Ministry, 2015). The first htx was inaugurated as an experiment in 1982; seven years later in 1989 htx became a permanent addition to secondary school education in Denmark(Jans, 2007; Olsson, 2007). In 1995 it obtained its current form as a three-year high school programme with direct entry from primary school (Jans, 2007). Htx initially struggled with being an unknown educational form and with general image problems. Today, however, this educational form has existed for almost 40 years and is now generally recognised as an equal and indispensable part of Danish STEM (science, technology, engineering, mathematics) and vocational education (Olsson, 2007:7) What differentiates htx from other secondary school programmes in the Danish educational system (such as stx and hf, which offer a broad general education, and hhx, the business high school) is that project-work is central to the curriculum (Ulriksen et al., 2008) and, therefore; based upon problem-based learning (PBL) (Henriksen, 2016a). This is especially true for the central subject areas 'profile subjects'; one of these 'profile subjects' is Technology.

2 The subject of technology

The subject of technology is available to take at both A and B level. The students at the first and second year of their study (age 17 – 19 years) at htx have Technology at B level, while the students at the third year (age 19 – 20 years) can choose Technology at A level. In this subject area at both A and B level students address the relationship between technology and society (Danish Education Ministry, 2015, 2017). As Henriksen (2016a:125) puts it, the subject's goal formulations are all characterised by a 'social-technical' concept of technology (Trist & Bamforth, 1951; Müller et al., 1984). The subject area has its basis in social issues and analyses of technology and community development. Further, its starting point relates to the interplay between technology, knowledge, organisation and product. Social scientific, technical, and scientific knowledge are combined with practical work in groups (Henriksen, 2016a:125). The technology subject consists of topics such as materials and machining processes, technology and environmental assessment, product development, production and marketing. Its general aim is to develop students' understanding of broadly interdisciplinary project work as well as developing their documentation and presentation skills. Technology A also includes subjects such as quality and environmental management, strategy, marketing, logistics, costing, etc. (Htx curriculum 2017; Henriksen, 2016a:125). As project work is the htx guiding principle, teaching is regularly organised as projects with the following as the basis for such activity: projects, group work, individual work, and teacher-led classroom teaching. This approach provides students with the possibility of being active in shaping the educational content, and in suggesting how projects could be approached (Ministerial order, 2017; Henriksen, 2016a:126).

With the regular teaching organised as projects and that being mixed with teacher-led classroom teaching the roles of the teachers teaching the subject of technology at htx becomes one of a hybrid characters as they, when working with Problem-based learning, can be said to be placed in a position between being a teacher in the more classical sense and functioning as a facilitator at the same time. This hybridity presents a challenge for the teachers as they experience that it unfolds an even wider variety of roles for them to fill out within the framework of the subject.

To further understand the challenges that arise for teachers in teaching the technology subject, it is pertinent to first introduce Problem-based learning and afterwards present the realities of what is happening in the classrooms to clarify the breadth of the hybrid role of the teachers but before doing so we firstly unfold the method for collecting the empirical data used in the article.

3 Method

Our empirical data is based on observations and interviews at the Danish higher technical examination programme. The observations were conducted at htx in Aalborg and Kold College in Odense, Denmark. The observations were conducted as observation with participation as we had an interest in studying the field from the "inside". From the "inside" must be understood as we as researchers interact with the field we want to investigate, in this case the subject of technology (Krogstrup and Kristiansen, 1999:54). We observed in two different classes during a project period and discussed our findings with the teachers. At htx in Aalborg we observed at third-year level and at Kold College in first-year level. The interviews were conducted as semi- structured interviews with three different teachers from htx in Aalborg. The teachers from htx in Aalborg are selected based on two criteria: They teach technology subject and they have different professional backgrounds. The observations were subsequently used directly from the field notes and the interviews were transcribed

- both for the use in the article.

4 Problem based learning as a framework

In Graaff and Kolmos (2007) Problem-based learning (PBL) is defined as a learning philosophy and a set of learning principles. Graaff and Kolmos (2007) and Kolmos et al. (2009) summarizes the main learning principles that can cross different PBL models in three approaches; learning - contents - social. The problem is the point of departure for the learning process. The problem creates the context and is central for the motivation of the student. Often problems are solved in time limited projects, with contents considered interdisciplinary and in groups where collaboration between students is necessary. In the groups there can be different degrees of participant-directed learning (Kolmos et al, 2009:11-12).

There are many different implementations of PBL. What works at Aalborg University does not necessarily work at htx. Savin-Baden (2007) defines five PBL models or modes with six dimensions, and with inspiration from that model, Kolmos et al. (2009:15-16) develops a model based on seven elements, that all need to be aligned in a PBL curriculum (see figure 1).

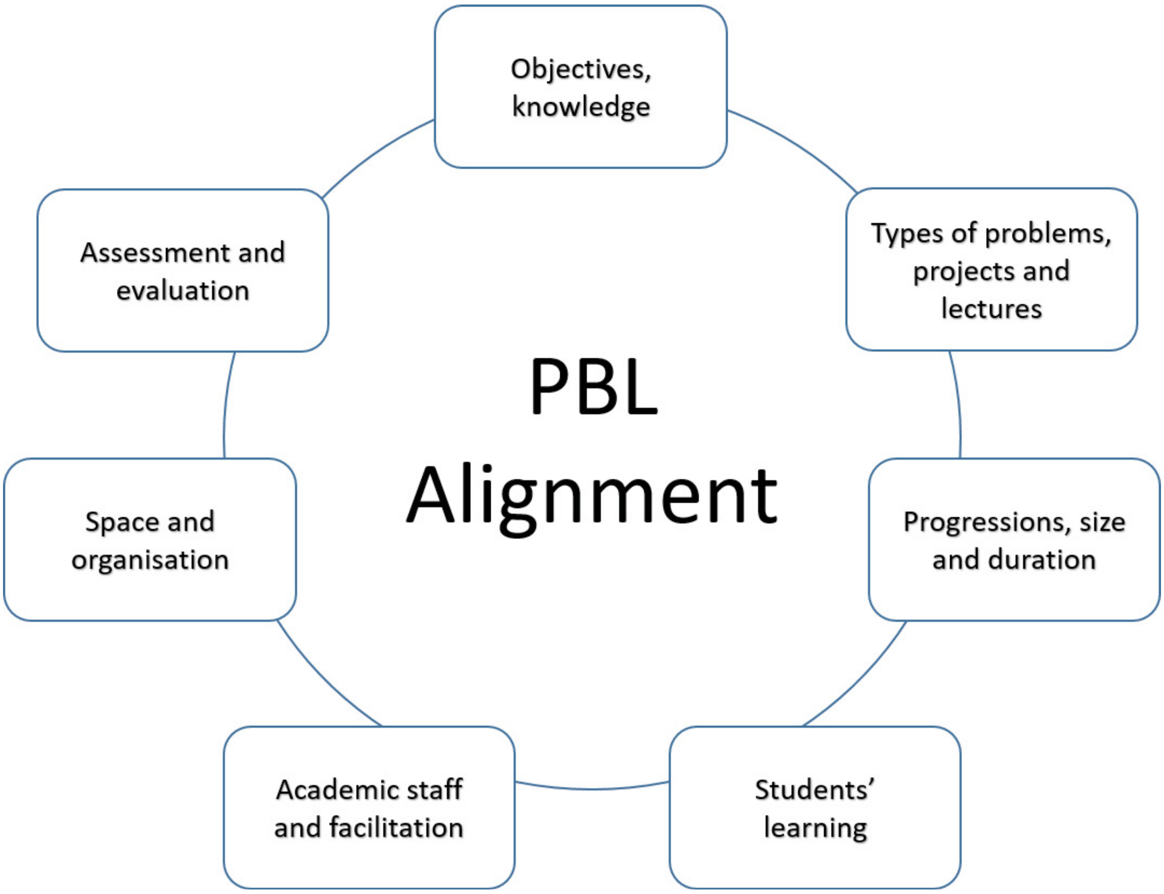

Figure 1. PBL alignment of elements in the curriculum (Kolmos et al, 2009:15)

The alignment of the elements in the curriculum means that changing one element will result in a change in the other elements. Combining the model from Savin-Baden (2007) with the model of PBL alignments result in a model with many variations of PBL in practice. The many variations in PBL practices are indicated as seen in table 1. The discipline and teacher-controlled approach and the innovative and learner centred approach (student centred approach) are the two extremes with many points in between.

Table 1. Spectra of PBL curriculum elements (taken from Kolmos etal., 2009:16)

Curriculum element	Discipline and teacher-controlled approach	Innovative and learner centred approach (student centred approach)
Objectives and knowledge	Traditional discipline objectives Disciplinary knowledge	PBL and methodological objectives Interdisciplinary knowledge

Types of problems and projects	Narrow Well defined problems Disciplined project Study projects Lectures determine the project	Open Ill defined problems Problem projects Innovation projects Lectures to support the project
Progression, size and duration	No visible progression Minor part of the curriculum	Visible and clear progression Major part of course/curriculum
Students' learning	No supporting courses Acquisition of knowledge Collaboration for individual learning	Supporting courses Construction of knowledge Collaboration for innovation
Academic staff and facilitation	No training Teacher controlled supervision	Training courses Facilitator/process guide
Space and organisation	Administration from traditional course and lecture based curriculum Traditional library structure Lecture rooms	Administration supports PBL curriculum Library to support PBL Physical space to facilitate teamwork
Assessment and evaluation	Individual assessment Summative course evaluation	Group assessment Formative evaluation

The above should be seen as a framework for PBL in higher education and the approaches that fall within this framework. Since the article's desire is to gain an understanding of the teachers' roles in relation to working with PBL in htx we in the following work with four ideal types of teaching in secondary schools (Zeuner et al. 2007) to draw parallels to the above PBL framework.

5 Methods for teaching in secondary education

Zeuner et al (2007) defines four ideal working methods for teaching in high school. The communication (mediated) orientation of work, where the teaching is centred around the teacher as a representative of the knowledge - high teacher management. The dialogically oriented way of working, where the teacher is a participant in the learning process. The task-oriented way of working, where the teacher acts as instructor. Finally, the project-oriented way of working, where the teacher acts as a consultant (see table 2).

Table 2: Part of table with four ideal types of teaching from Zeuger et al (2007:371).

	The Communication oriented High Steering Distance Representative Classroom	The Dialogically oriented Low Steering Proximity Participant Classroom	The task oriented High Steering Proximity Instructor Study Room	The project-oriented Low Steering Distance Consultant Practice Room
Variations	The lecture The exam (overhøringen) The exemplary experiment	The informal conversation Teacher talk with subsequent discussion Student presentation with subsequent discussion	Management degrees in relation to substance (eg questions) Management degrees in relation to communication (teacher-student conversations)	Degrees of management in relation to: - the length of the project - choice of material - problem formulation - product requirements -student-teacher-conversations during the process

Zeuner et al. (2007) mentions that the teacher types of working depend on the situation. The communication- oriented way of working seems to be most suitable when the subject is difficult - abstract, conceptual etc. (Zeuner et al., 2007:372). This way of working is what is considered as the more classical teacher role, whereas the project-oriented way of work is considered as a facilitator role (see table 2). Regarding project-oriented ways of working Zeuner et al. (2007) comments:

> “In relation to the 1st grade teaching that we have mainly followed, it becomes clear that the challenge for project work will be to establish the right balance between academic discourses and students' own learning processes” (Zeuner et al., 2007:374).

Another argument that emphasizes this point is made in Jeppesen (2020) in relation to htx where the degree of problem orientation is varying from teacher to teacher. Here the teachers do agree that the students have to do project work on their own, but they disagree of how much the teachers should control the process during project periods and introduce academic discourses or the focus should be more on students’ centeredness. The question of who is actually in charge of organising the project is thereby being raised. Is it the teachers or the students? And if the students are responsible, when should the responsibility be transferred to them? The teachers simply agree to disagree. However, what do we see in the classroom?

6 In the classroom

6.1 First-year

Working with several teachers and observing in different classrooms at htx we got insight into the various roles the teachers must take on to teach in the technology subject.
It became very clear from the beginning, visiting these two classes at htx, that the teachers as part of their role in the classroom must be able to fill the role of a classic teacher and perform classic teacher- led classroom teaching which relates to the discipline and teacher controlled approach as described in table 1- in relation to PBL in higher education and to the communication oriented approach in table 2 - related to ideal types in relation to teaching in secondary school. It is especially clear in the beginning of the first year of the study programme where the teachers make use of classicclassroom teaching more often than not in form of lecture etc. and thereby leaning towards a more teacher- controlled approach. When asked about if there is a difference in how much the teachers use different types of teaching approaches and thereby take on different roles as teacher teaching the technology subject a teacher answer:

> “ Yes, less and less teacher management (...) We start with PU (Basic course in product development at the first year of the study programme) and we are actually there all the time (...) saying: “now you have to do this now you have to do that”. And then when reaching the second year of the study programme the good students, especially in the technical science subject, can manage it themselves (...) As I told you earlier when the students reach the third- year of their study they should be able to control it themselves (...) Then I should dare to let them work freely (Teacher 3, 2019).

In the above quote the teacher expresses his way of teaching and thereby also showing that the roles he takes on teaching changes over time. At the beginning of the first-year of the study the teaching is very teacher- controlled (table 1) and communication oriented (table 2) and the teacher thereby takes on the role of a *classic* teacher using a more teacher centred approach. The teacher tells the students what to do and when to do it. It is also expressed in the quote how that all changes during the second- year of the students’ study where the strong students figure out how to manage doing project work themselves. Further, in the students third-year of study all of them should be able to control the project work themselves and the teacher should dare to let them do so; thereby accepting the role as a *facilitator* creating a room for an innovative and learner centred approach (table 1) or a project- oriented approach (table 2) which aligns with the underlying PBL principles in the technology subject.

That fact that the teachers take on the role of *a classic* teacher teaching first-year students is further emphasized when visiting a second school. The teacher in the class we are attending is preparing to teach the students’ some theory which they will need later to write their projects and develop their products and then the following happens:

> "The teacher sets out with very classical teaching-led teaching from the start of the lesson. Today's topic for the lesson is sensory theory and basic tastes, logbook, collaboration contract, groups and Adizes four leadership roles. The teacher starts out with showing the students a program about how to retrain the sense of smell. Afterwards the teacher follows up on whether or not the students have read the material for today's lesson by asking the class directly. Two students raise their hands. Subsequently, the teacher embarks on a thorough review of sensory theory including the five basic flavours; sour, sweet, salt, bitter and umami" (Field notes, 14.11.2019).

From the field notes it is clear that the teacher in this classroom accepted the role as a *classic* teacher and thereby, using a teacher centred approach as the teacher controlled the teaching communicating, in this case sensory theory, to the whole class and leaving room for the students to approach the teacher and the rest of the class and ask questions if needed. It also seems the teacher takes on this role as, when asking the students, only two of them have done their homework and read up on the theory for this specific lesson. Then it seems even more pertinent to give the students a thorough review of the theory as they cannot move forward in the process of their project work without it.

It seems that there are also other reasons as to taking on the role of a *classic* teacher and using a teacher centred approach, than having to repeat material to the student, as they did not prepare from home. One of them is teaching inexperienced first-year students. This is expressed by a teacher in the below quote:

> "(...) we also have a great challenge when we give the students a project (...) of a three months duration (...) the students cannot grasp it (...) so you have to rush them all the time (...) And that makes it more or less teacher-led and not really project work" (Teacher 1, 2019).

In the quote the teacher mentions the duration of the projects the students have to work on as a reason why he falls back on the role of the *classic* teacher when working in the technology subject. The students can't grasp or oversee projects that last for months at a time and he as a teacher then has to push the students to finish making it more teacher- led that actual project work as is the intention in the subject. It is also implied that the teacher functions as a *safety net* for the students when rushing them to finish all the elements contained in the projects to make sure they are able to hand in. Another thing that influences the role of the teacher and the teaching method being applied in the classroom is the general formation of the students. In the following quote it is emphasized just how much focus there is on that in the students first-year of study: *"There's a lot of focus on general formation at the first-year level"* (Teacher 5, 2019). When entering a technology class, at first-year level it is very clear that the teachers have the role of an *educator* e.g. in terms of keeping the level of noise in the classroom down to a minimum. A role that seems to be characterised by a more teacher-controlled approach (table 1) or communication-oriented approach (table 2). A conversation between a teacher teaching technology at first and some of the students visualises the role of an *educator* very well. In this specific example the teacher notices a group of students standing across the room talking to other students when they should be working on their own projects and the teacher initiates communication with the students:

> "What are you doing over there?" (...) We are helping with the timetable (students) (...) Okay so four is helping three? (...) Yes (students) (...) Okay I think you should go over here again" (Field notes, 14.11.2019).

In the conversation between the students and their teacher the teacher advised the students to go back to their own seats instead of hanging around some of the other students that are still working on their timetable and in doing so the teacher is trying to affect the students' behaviour in the classroom by taking on the role of an *educator*. This is done in a more direct tone when the teacher presently has assumed another role. In this case the teacher has taken on the role of a *classic* teacher, teaching the class from the blackboard, but feels the need to step out of that role because noise starts to spread across the classroom and to stop the noise the teacher says to the whole class: "*You have to look up here now*" (Field notes, 04.12.2019). Further she adds comments for specific students not paying enough attention: "*Martin sit down*" and "*Jonas you are smiling you are not listening*" (Field notes, 04.12.2019) and in doing that shifts to the role of an *educator* before returning to the role of the *classic* teacher. In the first-year of the students' study the teachers also feel they have to do a lot of scaffolding: "*There is a lot of scaffolding at the first-year level. At the second- year level it is much easier. Then you say brainstorm and then they know what to do*" (Field notes, 04.12.2019). The teacher here is indicating that there is a lot of scaffolding to do in the students first-year indicating that the teachers have a role as the students' *safety net* making sure the students acquire the set of competences they need to be able to continue their studies. After the first year it changes as the students then know many of the concepts and methods used in the subject of technology.

6.2 Summary first-year

From this first part of the analysis it is clear that a large part of being a teacher teaching the subject of technology in the first-year at htx is handling a hybrid set of teacher roles such as; the *classic* teacher, the *educator* and the *safety net*. All of which are very teacher controlled and thereby can be identified as a more teacher-controlled approach or communication-oriented approach. At the same time, it is identified that there are different reasons as why the teachers take on these roles. Some of these reasons seem to be; the students are not experienced in doing projects yet, the students need teaching in theory and methods relevant to their projects, the students do not always prepare for the lectures and the students still lack the general formation related to attending an education in secondary school

6.3 Third-year

Starting up a project in the students third-year of study takes place differently than the previous years. Below is a description of an observation from a third-year class where they are just about to start up a new project period. This project period covers the last project they will have to do while attending the Danish higher technical examination programme:

> "The teachers start out by laying out the outlines for the coming project period. Afterwards the teacher emphasises that she now longer is their teacher but only takes on the role of supervisor. Subsequently, the students withdraw to their groups and start working" (Field notes, 03.02.2020).

The teacher therefore in the beginning of the lecture expresses explicitly to the students that her role has changed from the previous project periods. In relation to this last project they have to do the teacher is no longer the teacher implicating that the students should have learned everything they need to know by now and that they now have to prove that. The teacher can therefore no longer take on the role of a *classic* teacher. Instead the teacher, for this last project, will take on the role as a *supervisor*. Thereby the control of the overall project is shifting from the teacher to the students. In the observations from the field notes it is also shown that the students accept that shift of the control willingly and are taking on the responsibility.
A similar statement is made by another teacher in a another third-year level class:

> "All the students meet in the class in the morning. Eighteen students showed up. Subsequently, the teacher states that the students themselves are masters of their own time in relation to the project. The students manage their projects themselves and ask if they need help" (Field notes, 05.02.2018).

When the students reach the third-year of their study it is very evident that the focus has changed from a more teacher-controlled approach to a more innovative and learner centred approach or a project-oriented approach with low steering from the teacher. This is both evident when looking into the classrooms but also in the questions asked by the students. In the below observation from a third- year technical science class a small detail on the black board makes it clear that what is happening in this classroom is no longer teacher- controlled: "*On the board is a list of groups that need help from the teacher*" (Field notes, 06.04.2018). The students now have to keep track of - and ask for supervision themselves when they need it. The students are now more actively defining the teacher role. The teacher in this class is taking on the role as a *facilitator* letting the students be in control of their own projects.
At the same time it is also clear that the teachers at the students third-year of study hold back and are very conscious about how much technical information they provide the students with and how much the students gather for themselves which is illustrated in the below quote:

> "Now you have asked something and I have answered a little too much (Teacher) (...) That has been seen before (Student) (...) Yes, it has been seen before. That's because I get caught up in it (Teacher)" (Field notes, 06.04.2018).

The teacher is very conscious about the fact that he/she is taking on the role as a *technical* wizz helping the students answer technical questions they themselves should find answers to and at the same time also about the fact that he/she is not taking on the role as a *facilitator* like the teacher should as the students actually can handle a lot themselves at this stage. At the same time the students are also conscious about it and seem to know that the teacher sometimes gets caught up in answering their questions and find it somewhat enjoyable as the comment; "*That has been seen before*" is said with a big smile on the students face. The fact that the teacher is very aware that he/she digs too deep and explains too much when the students ask questions also emphasizes the next quote where another teacher expresses the following; "*The attitude is that the students should have learned it by now. If not, it's too late*" (Field notes, 05.02.2018). What is expressed in this quote is that in the third-year of the study programme the students should have learned by now what they need to know to write a good project and create a good product. Even so it seems there is a paradox between knowing the students should know what they need to know to do project-work and what is expressed in the quote before about answering a little too much on the students' questions and to that a teacher adds;" we *can't just let the students crash and burn here either"* (Teacher 3). In the quote the teachers express a paradoxical situation in which it is implied that they as teachers are caught between the choice of acting as a *safety net catching the students when they fall* or letting them *crash and burn* when doing project work.

6.4 Summary third-year

From the second part of the analysis it is clear that a large part of being a teacher teaching the subject of technology in the third-year at htx is about handling another hybrid set of teacher roles than when teaching the first-year students. Some of the roles the teachers have to take on when teaching third- year students are; the *supervisor*, the *facilitator* and the *safety net*. The first two roles; *supervisor* and *facilitator* are very innovative and learner centred or project-oriented where the students are controlling the projects themselves. The difference from the first- to the third-year is that the roles seem to be taken almost automatically by the teachers and the attitude is; "*(...) that the students should have learned it by now. If not, it's too late*" (Field notes, 05.02.2018). The one role that is still taken on by the teachers in the third-year is the role as a *safety net*. So even though the attitude is that students should know the material by now and if they do not it is too late the teachers in the utmost consequence still function as safety nets for the students - they step in and help if needed.

7 Findings and discussion

What can be seen from the findings in the classroom is that the teachers' role changes very significantly during the three years from first grade to third grade. Compared to table 1 and table 2 there is a movement from left to right in the tables. A move from a classical teacher role to a role that very much is the facilitator role. At the third grade the students know what to do. They know what is expected, when the teacher says 'brainstorm' etc. Still the teachers are caught in a dilemma. Shall they catch the students when they fall or let them crash and burn? That dilemma can be related to table 1 and the alignment of the curriculum in a PBL environment. At htx the students are not responsible for their own learning, like they are in the higher educations. PBL in higher education is characterized by a student-centred approach whereas in a htx context it is generally more teacher centred. At htx it is the teacher that is responsible for the students learning. It is clear when we observe a class where the students did not prepare for the project work. Then the teacher immediately switched for the facilitator role to the classical teacher role. How about preparation for the next time? Do the students read the text or wait until the teacher gives a lecture? Moreover, the alignment of the curriculum is important compared to the different maturity levels of the students. The students inthe first year cannot grasp a project duration for three months. It is too long. Whereas for third year students it may not be a problem. The role of the teachers needs and the curriculum need to be aligned with the point of departure of the students. Besides switching between the division of the teachers working areas in table 2 covering from the classical teacher to the project-oriented teacher - facilitator, the teacher in htx has other roles. Roles that are more social related or technical oriented like the social worker, the educator, the technical wizz, the practical helper, a master role in the workshop and not least the safety net. Roles that cannot be ignored looking at the overall teacher responsibilities in htx.

What about students in higher education using a PBL learning philosophy? Are the findings in this paper comparable to students in higher education or is it two different worlds? When students enter higher education like AAU they start working in a PBL environment. Students who have studied at htx are used to the challenge of working problem based. But what about students from other secondary school institutions like stx or hhx? They are not used to the PBL environment. When they enter the university the role for the teachers has changed totally. Now it is a facilitator role and the responsibility for learning has become student centred. The transition from secondary school to the university can be very hard for students not used to the PBL environment. Moreover, the mindset from the different students in a programme at the university cover the same range of PBL understanding as we have seen in table 1. That situation is comparable with the situation of the teachers at htx, with a very significant difference. At htx the teacher is responsible for the students learning which put them in a strong dilemma in a PBL context. They are not 'allowed' to let the students crash and burn.

8 Conclusion

The focus of the paper was to draw out empirical findings to clarify the breadth of the hybrid role of the teachers when teaching the technology subject at htx. The findings did support that the teachers at htx have a very complex and wide role. A role that changes from teaching first year students to teaching third year students and also a role that changes depending on the strength of the individual students. In relation to this it was found that the teachers not only have to shift between teacher- centred and student-centred learning (and the ones placed in between) the teachers at the technology subject also have to take on many other different roles ranging from the social worker and the safety net to the practical helper and a master in the workshop. Moreover, it became obvious that the role creates a dilemma for the teachers, trying to use PBL as a learning philosophy, however with a teacher centred responsibility for the students learning. This dilemma tends to be a restriction for the teacher in their teaching. They are not allowed to let the students crash and burn and the expectation from the students is that the teacher will be the security net in the end. Looking at figure 1 and the need of alignments of the elements in PBL calls for a clear support for teacher training to be able to work with this hybrid role. With recognition and knowledge of the hybrid role of the teachers of the technology subject at htx in more detail it is possible to identify some avenues for future pedagogical development of technology teaching at htx.
At the same time - knowledge of the role of the teachers teaching the subject of technology at htx in more detail and that being of a very hybrid character is valuable knowledge for the teachers and supervisors teaching at the first semesters at Aalborg University. With that knowledge it is possible to adjust the facilitation in the PBL environment to the different point of departures regarding first year students coming from htx, stx and hhx.

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Using a PBL perspective in continuing education for science and mathematics lower secondary teachers

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Abstract

For years, the need for inquiry- and problem-based learning (PBL) in primary and lower secondary education, within science and mathematics, has been addressed worldwide and requires support from a range of pedagogical sources. One important basis for such support is continuing teacher education. The present research builds upon data from a nationwide qualitative investigation (Hesselholt Henne Hansen et al., 2019), conducted as part of a feasibility study aimed at initiating a new STEM (science, technology, engineering, mathematics) graduate teacher programme in Denmark, leading to a Master of Science (MSc) in STEM teaching. The investigation identified continuing education needs of science and mathematics teachers and student teachers. We looked into the results of the qualitative portion of the feasibility study and investigated whether and how problem-based learning was being emphasized as comprising desirable content areas for continuing teacher education. Data were collected from 35 group interviews with 66 respondents: teachers from public and private schools, and teacher students. The results showed that PBL stands out as a desirable focus area. Other student teachers expressed an interest in including didactic-based topics that are related to PBL, e.g. differentiated teaching, engineering design, technology, and information communication technology [ICT] within STEM education. Furthermore, respondents expressed their desire for collaboration with other subjects (e.g. Danish and social sciences) in interdisciplinary teaching and, as well, the opportunity to immerse themselves in academic topics such as education for sustainability, climate education, technology, and including specific experiences with applied science, mathematics and recent research. Without being able to make a quantitative statement, it must also be mentioned that some teachers expressed no need or desire for further education.

Keywords: teacher continuing education, problem-based learning, K–9 STEM education, interdisciplinary,

Type of contribution: PBL research paper

1 Introduction

Throughout the world, the importance of science and mathematics teachers' continued professional development is increasingly acknowledged (Dillon, Osborne, Fairbrother & Kurina, 2000). In a Danish context, various studies (e.g. Rambøll, 2019; Undervisningsministeriet, 2018) have shown the need for capacity- building for science teachers. Nielsen (2012, p. 10) noted 'a need for science-specific teacher development in Denmark', but concluded that we know 'very little about the precise challenges and needs'. A report from Rambøll Management Consulting (Rambøll, 2019) noted, among others, the need for science teachers to receive capacity-building in their professional development. While 95% of physics and chemistry teachers and 88% of biology teachers have teaching competence in their subject, it only applies to 66% of geography and 60% of science and technology teachers (Rambøll, 2019).

For an international audience, it is important to say that the Danish teacher training for K–9 (primary and lower secondary school) is organized as a four-year programme at university colleges (UC). The Danish teacher education programme has four specialisations in the natural sciences: science/technology (Grades 1–6); biology (Grades 7–9), physics/chemistry (Grades 7–9); and geography (Grades 7–9); and two specialisations in mathematics: one in primary education (Grades 1–6) and one in lower secondary school (Grades 4–10). The teacher students normally specialise in three subject areas; Danish or mathematics must be one of these three. In a European context, this designates the teacher training programme as producing specialised teachers of education (European Commission, 2011a; European Commission, 2011b). The more teacher education has a strong relationship to practice (e.g. 16 weeks of practicum in various periods and forms) and teaching in the required subject areas (e.g. mathematics, Danish) integrates subject content with pedagogical content (Uddannelses- og Forskningsministeriet, 2020). Within the last few years, a new science teacher specialisation has arisen wherein teachers specialise in mathematics and three natural science subjects. This focus addresses interdisciplinary science teaching yet still does not contain additional subject matter (Petersen, Ahrenkiel, & Krossá, 2020).

Several years ago, the Danish Ministry of Education launched a National Science Strategy (Undervisningsministeriet, 2018), articulating the need for further continuing education of teachers in the natural sciences and, as well, the development of stronger professional didactic environments in educational institutions. This strategy has two national objectives: (1) encourage children and young people to take an interest in the natural sciences during primary and lower secondary school and to choose the natural sciences in upper secondary and vocational STEM programmes and (2) ensure that more children and young people achieve a high level of proficiency in science and vocational STEM programmes (p. 7). As part of this strategy, a new master's level educational programme for science and mathematics teachers was launched. As described in Nielsen et al. (2018), a consortium of five Danish universities and six Danish university colleges have applied for funding for preliminary research (feasibility study), development, and start-up of a K-9 STEM- related master's programme. The programme will start in autumn 2020.

Internationally, PBL has increasingly been adopted by K–12 teachers (Hmelo-Silver, 2004) – including within Danish science education – e.g. through introduction of problem-oriented engineering design in K–9 classrooms (Auener et al., 2018), and through an interdisciplinary science examination in 9th grade covering biology, physics/chemistry, and geography. In the aforementioned feasibility study, the qualitative part (Hesselholt Henne Hansen et al., 2019), we looked into the results of this effort and investigate if and how problem-based learning is being identified as desirable didactic and content areas for continuing teacher education by the teachers themselves. In this article, we specifically examine to what extent the teachers' answers reflect the need for further education in PBL and how it connects to a PBL approach, descripted in section 2.

2 Theoretical approach

2.1 Why PBL?

PBL indicates a process by which, according to Edwards and Hammer, (2006), increased students' motivation to learn and to focus their learning are present. Strobel and Barneveld (2009) point out that PBL is more effective, compared to traditional lecture based instruction, in relationship to long-term retention of knowledge and skills development. PBL also supports active, self-directed learning, students' experience of meaningful learning (Kolmos, Du, Holgaard, & Jensen, 2008), and students' motivation (Ertmer & Simons, 2014).

2.2 PBL approach: What is PBL in a lower secondary school context?

Barge (2010) delineates six principles in problem-based learning (PBL): *problem orientation*, *participant direction*, *project organisation*; *integration of theory and practice*; *team-based approach*, and *collaboration and feedback* (p. 9). *Problem orientation* means that a problem or challenge serves as the point of departure for learning (see also Holgaard et al., 2017). Barge (2010, p. 9) elaborates *participant direction* as 'students defining the problem and making key decisions relevant to the successful completion of their project work' (p. 9); *integration of theory and practice* enables 'students [..]. to see how theories and empirical/practical knowledge interrelate' (p. 9). A *team-based approach* means that students work together in project groups and use collaboration and *feedback* that, according to Barge (2010), allows not only the exchange of ideas but also assessments and critiques from both peers and, supervisors and thus an improvement in their learning result. Thus, 'the skills of collaboration, feedback and reflection are an important outcome' (p. 10) of the learning process. In our new study, based on data from the analysis of teachers' need for capacity building (Hesselholt Henne Hansen et al., 2019) we evaluate the degree to which it falls within these six principles of PBL.

In a systematic literature review, Merritt et al. (2017) found that there is 'no consistent definition of PBL' (p. 1). They define PBL as an instructional method (p. 4) and identify the following theoretical concepts from the relevant literature on K–8 mathematics and science education: (a) clinical-medicine education definition (learning by doing, students get presented to problems before instruction); (b) functional or curriculum design definitions (focus on implementing PBL in classroom with detailed steps); (c) constructivism or project- based definitions (learning through project work with real-life problems); and (d) conceptual-change definitions (inquiry-oriented science learning for early learners with focus on cognitive scaffolding) (pp. 4–7). Past research identifies the need for science teachers to master interdisciplinary approaches across STEM subjects (Bybee, 2013). By extension, the ability to handle such interdisciplinarity requires, amongst other attributes, teaching competencies in PBL. The relationship between PBL and differentiated teaching and interdisciplinarity is underscored by the following quote from Savin-Baden (2000):

> Problem-based learning is thus an approach to learning that is characterized by flexibility and diversity in the sense that it can be implemented in a variety of ways in and across different subjects and disciplines in diverse contexts. As such it can therefore look very different to different people at different moments in time depending on the staff and students involved in the programmes utilizing it. However what will be similar will be the focus of learning around problem scenarios rather than discrete subjects (p. 3).

3 Methodology

The qualitative data obtained in the current study is based on summaries of 35 focus group interviews with 66 respondents. The respondents were selected so as to represent the potential target groups of the STEM Teacher Master's Programme: K–9 public schools, private schools, and the Danish efterskole teachers, as well as teacher students (Hesselholt Henne Hansen et al., 2019). We conducted twenty-one interviews at K–9 public schools, six interviews with teachers from private schools and the Danish efterskoles (boarding schools), and eight interviews with teacher students (LS) – all respondents with a geographical spread across the country. The qualitative data were collected in connection with a feasibility study concerning the Master's Programme in 2019. In this paper, the data are interpreted with a focus on PBL supplemented with additional comments and observations.

A semi-structured design, based on two interview frameworks targeted at teachers and teacher students, were used. Researchers from Aalborg University, UC Absalon, UCL University College Lillebælt, University College Copenhagen (KP), University College North Jutland, and VIA University College interviewed the respondents. The interview frameworks were designed to inquire about teachers' needs for further training that would enable them to effectuate STEM-based learning units. The interview guide contained questions about professional background and possible content of the study. The interview formats were based on a table with possible content elements concerning science and subject-didactics elements, one of them concerning PBL. However, the respondents were free to bring up their own areas of interest and personal experiences. As described in Hesselholt Henne Hansen et al. (2019), every interview was audio recorded. After each interview, the interviewer prepared a written summary based on a template with professional background (education, subjects, and

Danish efterskole: In Denmark there is a long-standing tradition with boarding schools for grades 8–10. This tradition mainly originates within the ideas and initiatives of the clergyman, poet and politician, N.F.S. Grundtvig (1783–1872), and the teacher, Christen Kold (1816–1870). Based on their ideas about 'a school for life based on the living word', the first 'folk high school' for adults was founded in 1844 and the first 'free school' (private independent school) for children in 1852. Later in 1879, the first boarding school ('efterskole' in Danish) based on Grundtvig and Kold's ideas was established.

number of years of teaching experience) and possible content elements, mentioned by the respondents. These summaries were subsequently compiled for analysis; they were coded in Nvivo 12.0. Then, the summaries were analysed across school settings (i.e. lower secondary, private, or efterskole, or teacher students) relative to the coding category 'potential content of the graduate program'. The answers from the Danish respondents were translated into English by the authors.

4 Findings

Based on the data obtained, six content areas (A–F) were identified that reflect the respondents' input regarding optimal content for PBL-related continuing education. At the end of each content area, the authors related each element to the six PBL principles (described in Section 2).

Content Area A. Engineering – PBL and investigative competence: Respondents highlighted engineering and PBL as important methods to achieve interdisciplinarity, differentiated instruction, and increased pupil engagement. '[We could use] engineering, problem-based learning, because we can see that the students benefit from it' (Teacher 1, Hesselholt Henne Hansen et al., 2019, p. 8). Moreover, engineering and PBL are important for the development of inquiry competences. Respondents also mentioned modelling as a multidisciplinary way of working that can qualify an approach as PBL-based. The science teachers, on the other hand, were not so concerned with interdisciplinarity or PBL; they did, however, mention modelling as something that could improve instruction. Some science teachers expressed great interest in qualifying for teaching PBL-related curricula because of the project-organised interdisciplinary science examination in the 9th grade (Børne- og Undervisningsministeriet, 2019) covering the subjects physics/chemistry/biology/geography). Two teachers' (Teachers´ 2, 3, School A) even expressed the desire to in '[...] try project- oriented working methods – as a student'. Thy elaborated this statement and made the following proposal to the structure of the programme: They want to divide the study into subject areas that could be taught together when working with a subject/problem and simultaneously awareness of that particular topic. The teachers described a large common area of study, with inclusion of outside guest teachers and cooperation with other teachers on a given thesis in the Master's programme, as well as the possibility of sitting for an exam in a manner similar to their students. They highlighted issues from the real world as something they need to work on, see below. *Authors: The needs in this section can be reflected in problem orientation and project organisation.*

Content Area B. Interdisciplinary integration: The need for *interdisciplinary* integration between the different subjects in science and mathematics as emphasized as important but challenging. Only a minority of the teachers are educated in all three science subjects; therefore, there was a strong wish expressed by the respondents to gain knowledge of the other subjects and connect them to their own field of expertise. Moreover, the respondents expressed a desire for more relevant and realistic interdisciplinarity with separate subjects integrated within the various topics. The first spotlight is a quote from a teacher: 'The desire for the interdisciplinary field to grow, so that the education must deal with, just as the professional field regarding sustainability and engineering' (Teacher 4, School B). Respondents mentioned that interdisciplinarity with social studies could be relevant in relation to sustainability and climate education, especially for teachers who did not teach geography. The focus on integrating science subjects in an interdisciplinary way is pronounced. Here is a second excerpt from one of the dialogues:
Interviewer: 'Will such a master's programme make you say that now we have some teachers who can come out and teach a unified natural science?' Teacher 5 (School C): 'Yes. I hope so. Otherwise I really

just think you should discard the idea' (comment: provide the education).
Only teachers instructing in both mathematics and science have implemented an interdisciplinary focus. Several respondents saw inclusion of mathematics teachers in the science team as desirable but difficult to achieve – which, in turn, points back to their desire to focus on developing collegial collaborative formats and learning communities. 'We have a lot of kids who are scared of math ... when they see a graph, they panic ...there's also something like scaling. There is not the same "transfer" from mathematics to science as I could imagine' (Teacher 6, School D). Cooperation between the subjects Danish and science was also mentioned by many respondents. A wish for communities of practice between Danish teachers and science teachers was highlighted. Such cooperation was regarded as potentially strengthening pupils' competencies for source criticism and improving the reading skills needed to learn science. *Authors: The needs in this section can be reflected in problem orientation, participant direction, team-based approach, and collaboration and feedback.*

Content Area C. Authentic problems and external learning environments: These were highlighted as important with respect to their potential for producing high motivation among pupils and differentiating of teaching in the classroom between pupils with different level of knowledge. These are areas with a large demand for planning in order to be implemented in practice. There is both interest in and need for this area to be included in the Master's curriculum. Here, an explanation from the interviews is available (Teacher 6, School D): 'Authentic issues are something that motivate students. Therefore, it must be part of the education and how to transform scientific knowledge into teaching knowledge'. Another teacher (Teacher 7, School C) emphasized the contribution of authentic learning: 'There is a need to explore the possibilities for collaboration between school, business and other surrounding communities under the auspices of the open school concept from the Folkeskoleloven (Education Act) 2014 in order to present students with so-called authentic issues'. Teachers (8, 9, School E) express the importance of contact with universities and companies for authentic issues that they can apply in primary and lower secondary school. They point out an overall lack of practice in school education and insufficient possibilities for receiving instruction related to and tried in practice. Therefore, practice-relation and opportunities for teachers to make suggestions and then try then in their own teaching is an important issue in the programme. *Authors: The needs in this section can be reflected in problem orientation, participant direction, project organisation, integration of theory and practice.*

Content Area D. Differentiated teaching: One of the elements noted by the interviewees is the establishment of learning communities among pupils. According to the responses, the programme has to handle the various prerequisites and competencies that the teachers need. The teachers experience a considerable challenge in differentiating and formulating learning outcomes for all pupils, especially in relation to the format of the new exam and student inquiry. Furthermore, it is challenging for both teachers and pupils to work within interdisciplinary focus areas; the competence goals for science are especially challenging for pupils who, by and large, are not interested in or motivated by science. 'We have offers for the dyslexic students, but not for the students who feel "science-blind". How can you approach this in a professional way?' (Teacher 10; Hesselholt Henne Hansen et al., 2019). *Authors: The needs in this section reflects on problem orientation, participant direction, project organisation, team-based approach and collaboration and feedback.*

Content Area E. Development of own practice: The respondents mentioned action-based learning, communities of practice with colleagues, specific experience regarding applied science and mathematics and, as well, using newer research in teaching. An example from the extensive data illustrates these content elements: '(...) need for empirical research methods – more than what teacher education has provided – even in the bachelor modules. How to collect data in educational projects?' Teachers from School A felt it was important that highly project-oriented teaching in the Master's programme could be transferred into own practice. In continuation of the mentioned project-organisation, the lower secondary school teachers, especially at Grades 8 and 9, focused on interdisciplinarity as a focal point. This, again, was related to the joint natural science examination. However, there was no consensus on how to tackle the issue. Some teachers felt the focus should be on the professional qualification in relation to their subjects (School H), others emphasized a combination between professional qualification and didactics (School C and School I). According to some teachers, the focus should be on didactics and motivation. Additionally, time must be devoted to project-oriented working methods and experimental and problem-based learning. Furthermore, there must also be time for reflection. As the students have different focus areas (comment: as teacher in biology, mathematics, physics/chemistry and/or geography), time to complement each other is essential. That could be the focal point of education rather than focusing too much on didactic theorists. According to the teachers from School E, instead of theory, the focus is on increasing the ability to translate learning into something that is interesting and situated in real-life problems. Teachers from the private School F support the importance of theory-practice interrelation in the Master's programme, with experiments in their own school teaching practice, combined with project-oriented working methods. In this programme, they felt, it was quite important to be specific with respect to subject area and didactics (so that such curricula could readily be transferred to school science instruction. They highlighted the need to know where to look for kay research in their field, in order to continuously be updated on the latest research. This is supported by teachers from School G. According to development of their own practice, many respondents mentioned ICT (Information and communications technology), technology and understanding technology as important. For a large number of respondents, with the exception of for mathematics, using technology in a science context is challenging. *Authors: The needs in this section reflect problem orientation, participant direction, project organisation, integration of theory and practice, and team-based approach and collaboration and feedback.*

Content Area F. Opportunity for professional immersion: Respondents highlighted the opportunity for professional immersion. They particularly emphasized obtaining a higher level of professional mastery within the sciences – not only in their own subjects, but also in the other subjects included in interdisciplinary teaching. Besides, the respondents sought inspiration for effective source criticism and focused on how to apply materials related to recent research and expand the material from the digital platforms – often highlighted as superficial and deficient. *Authors: The needs in this section reflect problem orientation, participant direction, integration of theory and practice, team-based approach and collaboration and feedback.*

5 Discussion

Even though PBL was not often mentioned specifically, we saw a great variety in problem-based related issues. As shown in Section 4, content areas A– F reflect on the six *PBL principles* in different ways. However, in the discussion, we will take a closer look into these PBL principles: 'problem-orientation, participant direction, project organisation; integration of theory and practice; team-based approach, and collaboration and feedback' (Barge, 2010, p 9).

Problem orientation and project organisation

Regarding problem-orientation, many respondents mentioned the need for authentic problems. These can be brought into action by integration of external learning environments in STEM teaching. One of the reasons to do so is to support pupils' interest in STEM education (see, for example, Grunwald, 2016, 2019). Moreover, some of the interviewees directly mentioned PBL as an important part of the programme in relation to engineering. This fits with the developed engineering didactic for lower secondary schools (Auener et al., 2018), which requires further continuing education to support and develop investigative and inquiry-based competences. Still, the overall challenge of how concrete to make problem-based learning (Kolmos et al., 2008) in school science is not decidedly visible in the data. On the other hand, the need to develop teacher competences in scaffolding the pupils' learning process was brought up in the teacher interviews (see Auener et al., 2018, for further explanation). The question, however, is: to what extent is the understanding of problem orientation possibly connected to *project organisation* (another PBL principle) within the teacher's mind? Supporting student learning in a PBL project also requires the teacher's assistance in formulating the problem they want to solve. In this regard, differentiated teaching – a demand of some teachers – can be carried out but still requires additional pedagogical skills to practice in the classroom.

Integration of theory and practice

Additionally, the request for authentic problems, as expressed by the teachers and teacher students, reflects on the demanding challenge in STEM education to connect theory with practice in school teaching (see Grunwald, 2019, 2020). This is a third PBL principle. Another meaning with this connotation – and this is the prevailing view – is the need for a Master's programme with a coherent link between theory and practice. Teachers want to use theories or new research in the sciences in relation to their teaching. Some respondents expressed that they want a programme reflecting the teaching they need to practice in their own classroom. Competencies gained from the programme should be used in close connection with practice and vice versa. The outcome will be more motivated and skilled teachers and higher-quality instruction in the STEM topics.

Participant direction

The need for differentiated teaching is mentioned before, see problem orientation, to catch pupils' difference in interest, professional level (Nielsen, 2017). This calls for a project-organised form of teaching. Grant & Hill (2006, pp. 3–4) describe five factors in participant directed pedagogy that have influence on teachers adoption in the classroom: (1) recognition and acceptance of new roles and responsibilities; (2) comfort level in a more dynamic (physical) learning environment; (3) tolerance for ambiguity and flexibility in managing this new learning environment; (4) confidence in integrating tools, technology and networks into the curriculum and teachers' daily work within the new learning environment; and (5) integration of the new pedagogy to which with everyday life beyond the classroom. The extent to which this is a need and can be transformed for further education has to be elaborated.

The two last PBL principles, *collaboration and feedback* and a *team-based approach,* are only peripherally visible in the data. Here, further research is needed to provide knowledge of teachers' challenges.

Interdisciplinarity

At least interdisciplinarity is not a PBL principle, but important according to Savin-Baden (2000), see section 2. Respondents point out interdisciplinarity as an important topic, both in terms of integration with science subjects and cooperation with other school subjects as mathematics and Danish; mathematics, because it is obvious, and should be more frequently considered together with science subjects, and Danish because of the language issue and the fact that Danish, at least in primary classes, has most teaching hours (Rambøll, 2019). Interdisciplinarity is a precondition, as observed by different teachers, when working with authentic problems and important issues like sustainability and climate change. The results indicate that some teachers may feel challenged by interdisciplinary subjects and courses, and especially during the facilitating process in the run-up to the interdisciplinary exam in 9th class (Børne- og Undervisningsministeriet, 2019). In short, facilitating in a PBL context is linked to 'the overall concept for the teacher's role and function' (Kolmos et al., 2009, p. 10) with the teacher as a process-guide (ibid., p. 10) for pupils' learning. Nevertheless, results from the Rambøll report (2019) show that natural science teachers generally feel well prepared for interdisciplinary and common subject field activities. This is based on the fact that teachers in physics/chemistry, geography, and biology feel well equipped to teach subject-specific skills and knowledge areas in the classroom. This applies to those teachers who specialise in one or more different science subject areas, though not all are (see introduction). Nevertheless, the Rambøll report (2019, p.8) points out that 'there seems to be a greater need for professional qualification of teachers in science, just as science teachers in general feel less adept at teaching students the more general sciences skills and knowledge goals'. 'The four joint natural science competencies: investigation, modelling, perspectivation and communication) are central to students' learning throughout the school process.' (Rambøll, 2019, p. 86). The questions of how modelling can support a PBL approach in teaching and vice versa (Nielsen, 2017) need further investigation.

To get back to problem orientation as an essential PBL principle, this requires a different type of teaching from presenting 'pre-defined content' in a book chapter (Ertmer & Simons, 2005, p. 5). These authors point out teachers' need for new tools and strategies that can support the implementation of PBL principles like the facilitating of student inquiry and ongoing formative feedback in the classroom. In another article the authors distinguish between different efforts for the scaffolding teacher (Ertmer & Simons, 2014). They propose the following three efforts: (a) PBL planning, (b) PBL implementation, and (c) PBL assessment. In this context (a) involves the identification of the 'driving questions', the location of resources, and the creation of student ownership in the problem, (b) includes the creation of a collaborative classroom culture, the support of students' engagement, and (c) encompasses both the development of assessment methods/instruments and students' self-assessment skills. Nevertheless, these requirements are further challenged by the demand for developing an interdisciplinary didactic, where STEM education has to cooperate. Such a didactical STEM approach lacks development (Bybee, 2013). PBL can be a pedagogical or didactical frame to support this professional and didactical development.

6 Conclusion

The need for the integration of engineering and PBL was highlighted, as well as the integration of mathematics. However, it is also important as qualifiers for sustainability and climate education. However, we noticed that there are teachers in the study who believe that they do not need continuing education. In these instances, it could be interesting to investigate what professional and didactic challenges they face and what assistance they may need in order to improve their teaching practice.

It should also be mentioned that the research method has some limitations due to the different researchers involved in writing the summaries of the recorded interviews. This has probably resulted in different focal points, depending on the interviewer's professional background and interest.

At the content level, the K-9 schools science and mathematics teachers and student teachers who were interviewed expressed a need for interdisciplinary integration, because integration of the different subjects of science and mathematics is challenging. Focus for the teachers has been the interdisciplinary exams in science. Moreover, they expressed a wish to work with authentic problems and to experience more cooperation with the surrounding society regarding the problems. The argument for that is more motivated students and a need under the auspices of the open school concept. Engineering, PBL, and investigative competences are directly mentioned as possible content; engineering because it is important in relation to interdisciplinarity, differentiated teaching, and the motivation of the students. With the introduction of engineering in Danish lower secondary schools, there is a demand for PBL and thereby a need for a competence boost for the teachers. However, to support the teacher's continuing education for developing an interdisciplinary STEM didactic, new didactic approaches, including PBL, are needed to help teachers with planning, implementation, and assessment of teaching.

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Tools for Scaffolding Educators' Project Design Process

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Abstract

Some educators who are new to project-based learning have difficulty envisioning a project that is based on an authentic, ill-structured problem, connects to course learning outcomes, and that will engage students at the appropriate level of challenge. To support educators in the process of identifying projects and designing project-based courses that meet these criteria, three tools were developed and implemented in a year-long, cohort-based course redesign program at a large research university.

To date, these tools have been utilized with 20 faculty from different disciplines in three separate cohorts to design projects and create course syllabi. Feedback has indicated that designing with the end in mind and visualizing course content hierarchically were new ways of thinking for these faculty that were helpful in the design of their projects and course syllabi.

Keywords: Course design, projects, advance organizer, mapping, faculty

Type of contribution: PBL best practice

1 Introduction

Authentic projects can move students beyond facts and theory to practical application, and provide opportunities for students to integrate disciplinary knowledge and real-world skills. Authentic projects are based on a problem, issue, or topic that exists in real life, or that presents the same type of cognitive challenges as those in the real world (Savery & Duffy, 1996). Further, students in authentic learning environments have reported significant positive changes in their perceptions of their own problem solving abilities and preparedness for their professions (Dunlap, 2005).

To realize the potential of authentic projects, project-based courses must be carefully designed. Because many educators at the author's large research university do not have experience with this process, a year- long, cohort-based professional development program was developed. A portion of the program was focused on helping faculty participants to envision a project that is based on an authentic, ill- structured problem, that connects to course learning outcomes, and that will engage students at the appropriate level of challenge. To support educators in the process of identifying and designing projects that meet these criteria, three tools were developed and implemented.

The first tool is a worksheet containing a set of prompts designed to elicit information about what professionals in the relevant field do—including what complex problems they work to solve, the kinds of products they create or services they deliver, the ethical challenges they face, and the global and social challenges they are grappling with. The second tool is another worksheet—this one designed to scaffold backward planning and identification of what students would need to know and be able to do to successfully complete a selected project, including cross-disciplinary skills. The third tool is a hierarchical concept map designed to continue the backward planning process. In this part of the process, participants identify—at a more granular level—the knowledge and skills students would need to achieve the higher level concepts, mindsets, and skills, and represent the relationships of those components in a hierarchical diagram. The concept mapping process elicits the information necessary for the blueprint, which drives course activities, assignments, and readings.

To date, these tools have been utilized with 20 faculty in four separate cohorts (each with 4-6 participants) to design projects and create course syllabi. Feedback has indicated that designing with the end in mind and visualizing course content hierarchically were new ways of thinking for these faculty that were helpful in the design of their projects and course syllabi.

2 Context

The tools were developed for use in a faculty cohort program supporting project-based service-learning course design. The program was co-designed, co-developed, and co-facilitated by the director of service- learning and an associate director of the teaching and learning center (with an extensive background in teaching and research on PBL) at a large research university in the Northeastern United States.

The ongoing, year-long project-based course design program has been offered four times, with a total of 20 faculty participants, from various disciplines, completing it thus far. All full-time faculty, across disciplines, are invited to apply each spring, and participants are selected based on alignment of their goals and interests with those of the program. Past participants include faculty from the writing program, philosophy, communication, music, engineering, human services, marine biology, speech and language, and physical therapy. The goals of the program are to support faculty in designing project-based courses that are pedagogically sound, in collaboration with community partners, and that emphasize community impact.

While service-learning courses may involve direct community service, such as tutoring, for example, this course design program encourages and supports a project-based approach. Because faculty participants enter the program without experience with project-based courses or systematic course design processes, much of the program is devoted to developing their knowledge and skills in these areas while scaffolding development of a “course blueprint” for a project-based approach for their current courses or new courses. The tools that are described here serve as scaffolds for parts of the course blueprint. The tools present a novel way to support project-based course development.

3 Theoretical/pedagogical frameworks

The tools that were developed to support the project-based course design process in this program are rooted in three theoretical frameworks: 1) A cross-disciplinary skills framework called Self-Authored, Integrated Learning (SAIL); 2) Backward Planning; 3) Concept mapping.

3.1 Self-Authored Integrated Learning (SAIL)

Self-Authored Integrated Learning (SAIL) is a framework that was developed at Northeastern University (Northeastern University, 2019). It is comprised of 52 skills that span five dimensions of human growth and development (Intellectual Agility, Global Mindset, Social Consciousness and Commitment, and Well-Being), as well as a set of “foundational masteries” that includes skills such as self-directed-learning, communication, critical thinking, and collaboration/teamwork. The framework, which is being leveraged in curricular and co-curricular learning opportunities across the university, was motivated—in part—by employer skills gap research that highlights skills deficits of recent graduates. According to a 2013 AAC&U survey, 93% of employers say critical thinking, communication, and problem solving skills are more important than the graduate’s major. Another motivator for the framework is the call from educational accreditation bodies for educational programs to go beyond technical skills. For example, ABET (Accreditation Board for Engineering and Technology) requires U.S. engineering programs to “demonstrate that their students receive the broad education necessary to understand the impact of their solutions in a global, economic, environmental, and societal context and attain an understanding of professional and ethical responsibility” (Trbusic, 2014).

In the context of the project-based course design program, the SAIL framework provided the language for faculty participants to identify the cross-disciplinary skills most important for their students to develop during their course project work. Faculty are expected to integrate the support of these skills into their curriculum. While some of the skills are naturally being activated and practiced through project work, the curricular integration of the skills requires rethinking and repackaging course content.

3.2 Backward Planning

Backward planning (Wiggins & McTighe, 2005) is a widely accepted approach to course design that begins with identifying a student-generated product that will serve as “evidence of learning” of the big ideas for a course or unit of instruction. Once the evidence of learning (which also serves as the summative assessment) has been identified, the instruction is planned from there. Examples of student-generated products include a proposal or a deliverable created for the project sponsor, such as a web site, a marketing plan, or an evaluation. The deliverable is typically accompanied by a presentation and reflection, through which students articulate their reasoning and rationale for decisions made, their problem solving processes, and what they learned about themselves as learners. The backward planning approach served as the basis for the course design process in the program.

3.3 Concept mapping

A concept map is a visual representation of knowledge (Novak & Gowin, 1984). In the project-based course design process, faculty participants applied the concept mapping process to illustrate their project deliverable (evidence of learning), the key concepts that are enveloped by the project deliverable, and the knowledge that makes up those key concepts, in a hierarchical diagram. The concept mapping process facilitated the identification of high level modules or units of instruction. These three frameworks informed the development of the three tools that are described here.

4 Implementation

This course design program is designed, primarily, to encourage and support a project-based approach to service-learning that incorporates cross-disciplinary skills as an important part of the curriculum. Most of the faculty in this context have a significant degree of flexibility and agency in determining the course content and structure. During the program, each faculty participant develops a "course blueprint," which serves as the basis for their course development, regardless of whether they choose to use a project-based approach or a direct service approach (such as tutoring, for example). The program begins with a day-long kick-off retreat in late summer, followed by six one-and-a-half hour meetings in the fall semester and six meetings in the spring semester. Some sessions focus on critical service-learning and working with community partners, and other sessions focus on course design. The split between these two major areas of focus is approximately 50-50. Each course design session scaffolds a component of the course blueprint. Specific topics and activities include defining learning goals, identifying student deliverables (evidence of learning) and assessment criteria (including cross-disciplinary skills), writing learning objectives, identifying constructively aligned scaffolds, developing reflection prompts, and planning strategies for teaching social justice. Between meetings, participants complete readings and develop drafts of materials. During sessions, they discuss concepts and give and receive feedback on their work. In addition, individual consultations have been conducted during the spring and fall semesters and over the summer, as needed. A Blackboard course site is utilized for threaded discussions and as a repository for workshop materials, participant work, and external resources.

4.1 Worksheet part A: Social consciousness and your course subject

One of the activities during the kick-off retreat was for participants to complete Worksheet Part A: Social Consciousness and Your Course Subject. The purpose of this worksheet is to stimulate thinking about real world projects and issues in participants' respective disciplines. Because many faculty tend to be focused on curriculum and textbook content, this step is important, as it stands to re-connect them with the work of professionals in their field, and highlight the relevance of their course content. The prompts on the worksheet are as follows:

1. Generally (at a high level), what kind of work do people in the discipline of your course do? Include the services they provide and/or the programs or products they produce. *Example: People in medicine cure illness and disease in people.*
2. What complex questions are people in this discipline working to answer? *Example: People in medicine are working to identify causes of diseases that are unknown.*
3. What social, political, or global issues are encountered in this discipline? *Example: People in medicine are grappling with the implications of innovations such as cloning and identifying gene mutations during prenatal stages.*
4. What moral, ethical, and personal issues are people who work in this discipline facing? *Example: People in medicine are in the position of making treatment decisions that can significantly impact a patient's quality of life, or even lead to death.*

After completing the worksheet, participants shared their responses and a compiled list of responses was developed and discussed. The discussion was leveraged to connect their responses to potential course projects. Table 1 shows example responses, paired with the follow-up discussion questions.

Table 1: Example responses to worksheet A prompts.

Compiled Responses	Follow-Up Discussion Connecting Responses to Potential Projects
1. The work that people in the discipline do • Thoughtfully create a solution to identified problems (engineering) • Develop remedies to preserve and improve coastlines and wildlife habitats (marine biology) • Express intended thoughts, feelings, and ideas in a manner that inspires and engages a specific target audience. • Communicate across languages and cultures in ways that bring about mutual understanding. (intercultural communication) • Develop therapeutic protocols and devices that reduce individuals' pain and improve their physical abilities (physical therapy)	What type of project would engage students in this type of work?
2. Complex questions they are working to answer • How can we improve life with new and improved objects and technologies? (engineering) • What are the root causes of marine life and habitat decline, and what are the best remedies? • How can we effectively communicate and distribute knowledge, experiences, and ideas with a specific target audience? (writing) • How can we better facilitate communication, address misunderstandings, and build relationships across diverse populations? (intercultural comm) • What is the best approach for optimizing an individual's physical movement, given their current condition, goals, and lifestyle?	What type of project would engage students in these driving questions?
3. Societal, political, and global issues • Who is and is not being served by the objects and technologies we are designing, and what are the long-term environmental and societal impacts of our designs? (engineering) • Who and what will be impacted, in the long run, of policy decisions intended to protect or improve the environment? (marine biology) • Whose perspectives are and are not represented by our writing? (writing) • During communication, whose norms are practiced, what imbalances of power are thereby	What type of project could lead to more equitable access to resources and capital?

created or reflected? (intercultural comm) • Who will have the time and resources to access the services and devices that we make available?	
4. Moral, ethical, and personal issues • Deciding which innovation to fund and pursue (engineering) • Deciding what the truth is (writing) • Deciding which policies to recommend (marine biology)	What type of project could give students an opportunity to grapple with these issues?
5. Staying attentive to the roles of language, identity, and power in communicating across cultures to avoid reinforcing systems of oppression (intercultural communication).	

4.2 Worksheet part B: Connecting potential projects with course content and cross disciplinary skills

After brainstorming some potential projects on Worksheet A during the kick-off retreat, participants are assigned the task of completing Worksheet B before the next session. Worksheet B has three steps. In Step 1, participants are asked to articulate the 3-5 key disciplinary concepts or skills that students must take from their course. This step is similar to Wiggins and McTighe's (2005) Backward Planning step of identifying a course's or curriculum's "big ideas." In Step 2, they are prompted to consider which of the potential projects that they identified on Worksheet A could potentially engage their students with these key concepts or skills. They enter 1-3 of preferred projects, based on which they believe will be most effective at engaging students in the key concepts or skills. In Step 3, they enter the SAIL skills and foundational masteries that are most essential for students to successfully complete the projects listed in Step 2. Selecting the skills through this backward approach, in the context of a potential project, helps participants select from the 52 skills in the framework.

After completing this worksheet, participants have narrowed their list of potential projects and identified what students need to know and be able to do to successfully complete these projects. This information becomes the basis for the project design. The three steps in this worksheet are summarized in Table 1.

Table 2: Three steps in Worksheet B.

Step 1 **Key disciplinary concepts and skills** – What are 3-5 key disciplinary concepts and skills that students must take away from this course?	**Step 2** **Preferred Project(s)** – Of the potential projects listed on Worksheet A, which ones might most effectively engage students with the course's key concepts and skills?	**Step 3** **SAIL Skills and Foundational Masteries** - Which skills and masteries are most essential for students to successfully complete each of these projects?
	1.	
	2.	
	3.	

4.3 Concept map

After completing Worksheet parts A and B, participants are instructed to select one project to pursue. With this project in mind, they will go through a concept mapping process, through which they break down the key disciplinary concepts and skills into more fine grained knowledge and skills, and identify that project deliverable that will serve as evidence of learning. The resulting concept map shows these elements in a hierarchy with the project deliverable at the top, the key concepts and skills below that, and the more granular and simple concepts in a row at the bottom, connected to their respective key concept or skill. The educators can then use this diagram to chunk and organize their project, and develop aligned instructional scaffolds. An example concept map is included in Appendix A.

Before they embark on the concept mapping process, we spend time explaining this process. We note that some content and skills are more broad and complex than others. We demonstrate, through examples, how broad and complex concepts can be broken down into more granular pieces of knowledge. For example, in order to be able to drive a car, the key concepts are skills might include: The rules of the road, operating the pedals, steering the car within the lanes, parking within the lines, and interpreting and monitor information on the dashboard gauges. Each of these key concepts and skills can be further broken down. For example, the rules of the road include when to stop, when to go, how fast to go, the importance of car safety checks, etc. Through this analysis, we can see that if we are teaching someone to drive, we will need a scaffold related to the key concept of rules of the road, and we can see what that scaffold needs to include. We facilitate an activity that allows them to work in pairs to practice putting concepts and skills in a hierarchy. We compare and discuss their responses and then give them the instructions for their concept mapping process.

4.4 Next steps

Based on their worksheet responses and the concept map, participants next move onto the blueprint document, which calls for detailed information such as assessment criteria for the project deliverable, specifics of the scaffolds, and resources that students will need at each juncture of the project. Finally, information from the blueprint is extracted and placed into the syllabus, including the week-by-week schedule.

5 Results

While there is no formal evaluation of the program, a survey has been conducted at the end of each cohort to obtain faculty feedback about their learning. During the first two years, an informal paper survey was utilized, and responses were not available for review at the time this paper was written. For the third and fourth years, an electronic survey was used, and the relevant responses are summarized in Table 3. The survey included questions about aspects of the program unrelated to the tools described above, and responses to those questions are not included here. The current cohort is in progress and therefore, the survey has not yet been administered. Each of these Likert-scale questions had four answer choices from “to a great extent” (4) to “not at all” (0).

Table 3: Responses to Likert-Scale survey questions.

<table>
<tr><td>To what extent have you achieved each of the following program outcomes?</td><td>Mean (n=9)</td></tr>
<tr><td>1. Identify learning activities and assignments that do and do not map directly to the learning outcomes.</td><td>3.5</td></tr>
<tr><td>2. Produce a course/project hierarchy that illustrates the essential generative, active, and knowledge level activities and topics for your course or project, and how they fit together to foster learning.</td><td>3.5</td></tr>
<tr><td>3. Produce a course/project design document that clearly articulates learning outcomes, formative assessments, and summative assessments, and how they fit together to foster learning.</td><td>3.3</td></tr>
<tr><td colspan="2">In what knowledge or skill area(s) did you develop most significantly through this program? What activities or resources had the most impact on your learning related to this?
• I developed knowledge of learning outcomes and how to assess an assignment in relation to learning outcomes.
• I learned to design a course hierarchy and how it can help to conceptualize a course that has depth, impact, and cohesion.
• I developed a better understanding about some of the goals in my discipline and how they related to course projects. The early brainstorming activities that we did were very helpful throughout the process.
• How to better align objectives within a project plan and then make sure that all assignments line up appropriately with the objectives.</td></tr>
<tr><td colspan="2">Additional Comments
• Both the course hierarchy and the course design with learning outcomes and assessments in a particular format were new to me. They were very helpful tools in creating the course. I plan to continue to use these methods for other courses as well. I am not a very visual person, so I was surprised with how useful the course hierarchy was. It really helps to see a course on one page.
• I think I need to do more of these to get better and feel truly effective at constructing course designs.
• Still working on connecting knowledge of the discipline (scholarly reading/writing) to the project.
• The course design is still a work in progress--it is taking many iterations. I want to create a version for my students. Not there yet.
• I have come a long way with backwards course design through this program and while I still need a little more specificity and clarity with the design doc itself, I am confident it will get there because the overall vision for the course has evolved so much.</td></tr>
</table>

6 Conclusions

Faculty who have completed the program have successfully used the three tools described here to identify appropriate authentic projects and design their courses. The course and project designs are founded on an authentic product that is to serve as evidence of learning, with cross-disciplinary skills integrated with disciplinary content and skills. The resulting designs provide the core material necessary to build a syllabus.

While there has not been a formal evaluation, each cohort has shared their final products and reflections on the process, and received feedback from their peers and from the program facilitators. Additionally, a survey has been conducted at the end of each cohort cycle to gather input about the participant learning process. Previous faculty participants reported that they have learned moderately to a great extent (means of 3.3 – 3.5 on a 4-point scale) on survey items related to the project tools. Our observations of the progression of participant work also suggest that the tools have effectively guided faculty through the project-based course design process. The tools have proven to help faculty envision their project, connect it to their discipline and create a cohesive project/course design that includes intentional and explicit support for cross-disciplinary skills.

While the program has evolved iteratively over the five years it has been running, the overall structure, activities, and concepts have remained fairly consistent. The modifications that have been implemented have for the most part been related to the sequence, framing, instructions, and examples to make connections across activities more clear and to ensure consistent use of language throughout the process. The survey comments, along with our observations indicates that at the end of the program, faculty are still in need of additional learning and support as they continue to flesh out their draft designs and create a syllabus. This highlights the challenges of this process for faculty who are new to backward planning and project-based learning.

Project-based course design is a complex process with intricately connected components. Further, many faculty do not have experience with project-based learning, backward planning, or intentionally and explicitly supporting cross-disciplinary skills. A carefully planned and executed professional development program can go a long way in supporting the process, and the three tools presented here can be a valuable part of that process. Ongoing practice with feedback are likely necessary for sustained effective design by faculty new to the process.

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Encouraging faculty towards the curriculum transformation of engineering programs

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Abstract

This work shows an experience stressed on the motivation of Faculty to design student-centred approaches for Engineering Education. This article describes a teacher-training program to encourage the change, by using active learning experiences that, in an exemplarity way, promote a shift in attitude among teachers strengthening two skills: collaborative work and communication, essential skills for PBL. The program considers four moment, namely: i) Interpretation, ii) Disruption, iii) Communication, and iv) Transformation. These moments take as scenario restyling traditional classrooms, which are renovated as Active Learning Classrooms (ALC). The first moment 'Interpretation' uses Design Thinking tools for rethinking the teacher practice and analysing roles of participants on learning-teaching experiences; there, the main objective is to empathize. In the second moment, 'Disruption,' participants develop activities related to novel topics for their performance field; in this stage, workshops offer a disruptive environment fostering divergent thinking. The third moment, 'Communication,' uses playful activities that allow teachers to comprehend the importance of this skill for collective work. Finally, the moment called 'Transformation,' introduces the PBL by using workshops and Hands-On activities. In these activities, Faculty designs a PBL intervention for a semester or proposes a new educational framework for an engineering program. About 80 teachers from different programs have participated in the program training with successful results; many student-centred experiences are emerging, where the new ALC play a role of a catalyst for the teaching transformation.

Keywords: Active Learning; Curriculum Transformation; Project-Based Learning; Design Thinking; Faculty

Type of contribution: PBL best practice

1 Introduction

In the curricular transformation, the management of change is one of the most critical challenges. According to (Moesby, 2004), it is necessary to complete six elements to guarantee a successful change. Among these elements are the vision, consensus, and skills, the lack of one of these will bring a different result.

Currently, strategies like PBL and CDIO are spreading in engineering programs. Both are approaches centred on students through encouraging activities that promote the exemplarity and collective work. Many contributions about the use of PBL and CDIO as ways to the curricular transformation show new approaches and interventions, where motivated teachers lead the change, and the feedback and performance of students have become the most remarkable results. However, transferring this knowledge to the whole University or School implies to sensitize to others, since a complete curricular transformation goes beyond a personal experience or a course. This work shows a strategy to encourage teachers towards to curricular transformation of engineering programs.

This work presents a general overview of a training program implemented for motivating the change in engineering teachers, which take the transformation of the classical classrooms to active learning environments as scenario. This training program centres on teachers through actions that involve them in active learning experiences at seeking teachers have become students, and they can assess the advantages and limitation of new teaching practices in student-centred approaches.

1.1 Context

This article presents an experience developed at Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia (UPTC Sogamoso). This is a Public University located to 250 Km from Bogotá, the capital of the country. The campus Sogamoso at UPTC has eight undergraduate programs that comprise an interdisciplinary Faculty. In which there are five engineering programs, namely Geological, Mining, Industrial, Electronics, and Computing Engineering, and three programs related to Management, Accounting, and Finances. Likewise, there are 14 graduate programs, including a PhD program in Electronics Engineering. All the undergraduate programs have arisen from the Context needs.

Sogamoso is a city located on the Andean Mountain (eastern mountain chain), in Boyacá province (in Colombia, provinces are called departments). Sogamoso's economy depends on several sectors like coal mining, cement, steel industry, and agriculture and agroindustry, the last ones favored by its wide rural zone. These sectors strongly influence the deepening of engineering programs, as well as the research and extension work of the academic community of UPTC. The campus Sogamoso has about 3000 undergraduate students, 600 graduate students and about 180 teachers, and it corresponds to approximately 12% of the total population of UPTC.

The institutional structure of the University and programs' framework are oriented mainly to traditional educational models, in which teachers have a primordial role in the teaching and learning process. Taking into account the challenge to educate global citizens that can give solutions to local contextual problems with an international view, the UPTC starts a transformation process in which the programs must renovate and update their educational frameworks. To face this challenge at UPTC Sogamoso, the research group in processing signals (DSP-UPTC) leads two strategies: 1) the design of new learning spaces and 2) a teacher- training program focused on student-centred approaches.

In this paper, the authors sketch the first strategy, as an important antecedent to describe in detail the second strategy in Section 2. Section 3 describes the moments considered in the training program. Finally, the authors present some feedback based on their observation during the training program and some concluding remarks regarding the developed experiences.

2 Teacher-training program based on ALC

2.1 Active- Learning spaces as a motor of change in engineering teaching

Understanding that teaching also comes from the environment and the learning spaces becomes the third teacher, after parents and schoolteachers (the first teacher) and peers (the second teacher), and considering that the learning environment also transfers information and help to construct knowledge. The proposed training program exploits the leaning space design as a tool −as it is stated by Bosch (2018) regarding to design− to transform the teaching practices of faculty. Therefore, the first strategy focuses on showing experience of curricular transformation centres on the use of new teaching and learning spaces for engineering education. Likewise, pedagogues have highlighted the importance of the near context for motivating the learning (Vygotsky, 1987), taking the learning space as a key element for promoting the interaction and communication among participants. Many Universities around the world have discussed the importance of the design of Active Learning Classrooms (ALC), some of these Universities that stand out in the design of ALC and that serve as a reference is the University of McGill, (Finkelstein, Ferris, Weston, & Winer, 2016), the Central Michigan University (Drake & Battaglia, 2014), the Pennsylvania State University (Rook, Choi & McDonald, 2015), and the University of Minnesota, (Whiteside & Fitzgerald, 2009).

In this first strategy that serves as a platform for the training program, the researchers took as a reference the principles for the development of learning environments of David Thornburg (2013) who proposed the design of environments using the physical space as a learning tool according to the students' needs . Analysing the context of the Universidad Pedagógica y Tecnológica de Colombia and detecting the teaching- learning needs, DSP researchers propose a new typology for Active Learning Classrooms, which is represented by icons that show possible interactions among participants (see Figure 1). This typology considers four kinds of ALC: Ideation as a thinking room, Transition that seeks to bridge traditional education to active learning, Collaboration as a space for working with others and Connection that provides a scenario for randomly gathering.

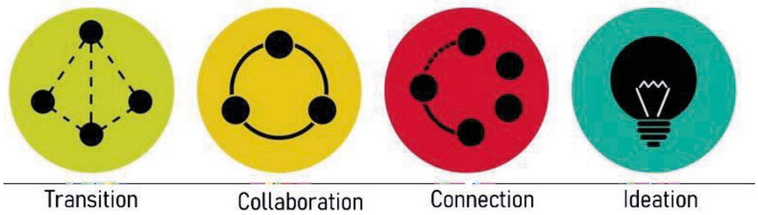

Figure 1: ALC typology of UPTC, taken from (Fernández-Samacá & Alarcón 2019a)

2.2 Design of Teacher training program

The appropriation of new approaches to teaching and learning, such as student-centred approaches in higher education may present barriers due to the conditions inherent to the institutional environment like the infrastructure, inertia of traditional curricular design, teacher attitude and students' expectations, among others. Therefore, a teacher-training program must be 'exemplarity' so it can motivate the curricular transformation, considering four moments labelled, respectively, like i) Interpretation, ii) Disruption, iii) Communication, and iv) Transformation. The first moment, 'Interpretation,' uses Design Thinking tools to rethink the teacher practice, and its main objective is that teachers empathize with their students and colleagues. The second one is 'Disruption'; there, participants develop activities related to novel topics for their professional field, fostering divergent thinking. The third moment is 'Communication' uses playful activities that allow teachers to comprehend the importance of this skill in work with others and for the successful execution of the projects. Finally, the fourth moment, called 'Transformation,' introduces the PBL by using workshops and Hands-On activities, in which Faculty is encouraged to propose a new educational framework for their courses or programs.

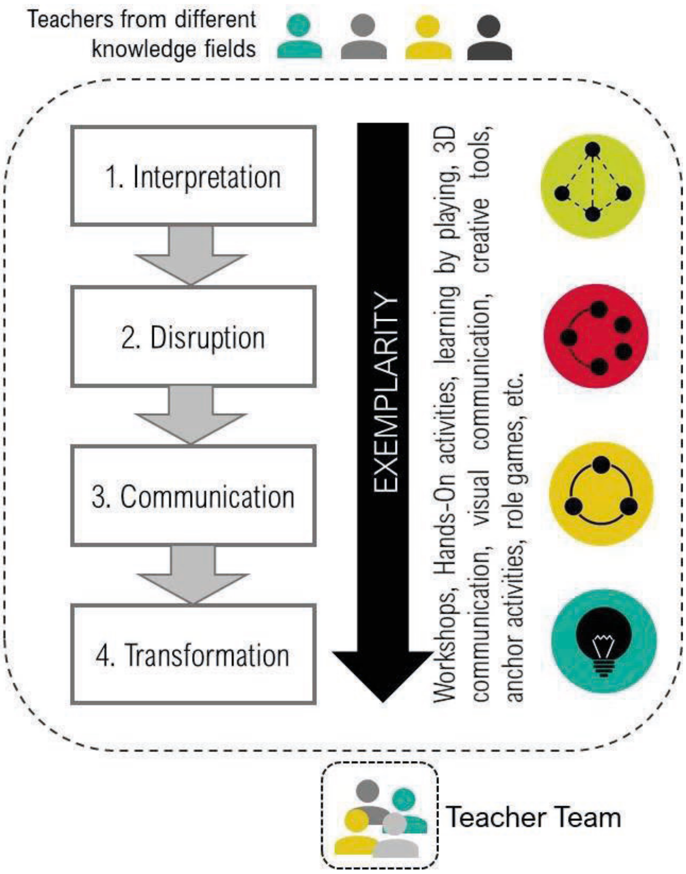

Figure 2: Teacher Training design, taken from (Fernández-Samacá and Alarcón, 2019b)

Thus, by using workshops, hands-on sessions, anchor activities and role games, among other strategies, researchers show how to configure an active learning classroom and how to use it for promoting a student-centred culture, consolidating, in turn, the collaborative work among teachers, see Figure 2.

2.3 Interpretation

This moment focuses on exploring creative tools of design thinking. The main purpose of this experience is to promote empathy in the teachers to transform teaching experiences, recognize participants in a learning experience, and encourage transformations that make the design of learning experiences more significant and attractive.

The Design Thinking (DT) is applied in this process how a method for identifying diverse problems of the context, involving participants actively through creative experiences that promote the collective work. The method has five phases Empathy, Definition, Ideation, Prototyping, and Testing, which were adapted to the teaching and learning process as Discover, Interpretation, Ideation, Experimentation, and Evolution. In this instance, this moment focuses on the first and second phases of DT, for exploring diverse techniques and creative resources (IDEO, 2012).

Interpretation comprises four experiences: i) Recognition of the teacher roles (e.g., Lecturer, expert, facilitator, etc.); ii) Understanding the student's role into the teaching practice; iii) Rethinking about the common teaching activities in the classroom, which becomes a demanding challenge in the curricular transformation; and iv) Ideation of alternatives for making new teaching experiences. The designed experiences allow teachers to have an exemplarity process, where they can apply several tools and instruments proposed from the design. This due to:

Firstly, the recognition of their roles as a lecturer and facilitator seeks to raise awareness about the importance of knowing the student as an actor of their classroom experiences.

Secondly, empathy bases a solid foundation for constructing ideas devoted to meaningful solutions for teachers. Where, empathy means opening up to new opportunities and getting people inspired to create new ideas, which can be revealing and gives a good comprehension to face the challenge of the curricular transformation (Chin, Blair, Wolf, Conlin, Cutumisu, Pfaffman, and Schwartz, 2019).

Figure 3: Empathy and experience map

Finally, creative tools, like the empathy map (see Figure 3) encourage teachers to reflect on their experience through a role-play for recognizing the need and student expectation in a learning experience. Moreover, the empathy map allows teachers to know the main characteristics of students and their main motivations, giving responses to questions about what students feel, see, hear, or think. These responses help teachers to find common points that can be projected in the redesign of learning experiences.

2.4 Disruption

This moment starts from the conception that teaching is a communicative act, and as any communicative act, it relies on language systems for expressing the contents and knowledge object of learning. From this perspective, it is essential to deepen knowledge of new and stimulating languages that achieve to adequately transmit contents and favour a full understanding, promoting in the participants, a significant learning process. The main purpose of the Disruption moment is discovering the teacher as a designer of learning experiences, as well as to stimulate to him/her towards the use of other ways of representing and communicating knowledge, supported by the basic principles of the propositional disciplines such as the design, and creation.

The fundamental principles of design and creation, such as shape, balance, symmetry, colour, texture, among others, can equate processes and uses, which are exposed and contextualized in any area of knowledge. These communicative principles have demonstrated its effectiveness for provoking satisfactory learning experiences, when are used with intentionality either by giving the value of a code or by using as a stimulus within a communicative praxis.

Researchers expect that the developed classroom experiences projected from these foundations, also favour the active and motivated participation of teachers, and the empathic gathering with the new knowledge, advocating not only to achieve the educational objectives in the classroom but also to remember the contents.

Figure 4: Learning experience about emotions and colours

At this moment of the training program, the chosen topic is "colour theory", it has been selected because it is not common in training programs for engineering teachers. For this workshop, the designed didactic material allows participants to understand the topic and demonstrate the importance of these communication tools to familiarize themselves in a very short time with the concepts and their possible uses in the classroom, see Figure 4. With the designed material, activities that develop rapid conceptual learning are proposed, which is reinforced through practical actions aimed at the immediate use of the concepts and encourages its argumentation based on the proposal generated for its application in other contexts by the group of teachers. These tools empower the development of other teaching alternatives that support permanent and changing actions, moving the axis of the educational process towards the student, for emotionally encouraging him/her, from curiosity, creativity, and pleasure in order to reach the planned. From this perspective, researchers expect that the activity carried out in the classroom can be spread in all the materials that the creative intention of the teacher promotes.

The context must motivate the result of this activation. For the individual construction of cognitive structures to take place, it is necessary to turn the classroom into an adventure guided by the dynamics of each group of participants.

The process of disruptive learning from the communicative foundations of the design stimulates curiosity, where the teacher proposes and designs activities for the interaction of learners and other activities that lead them to develop the experience. Thus, the student is responsible for discovering the activity in which he/she has been, as well as the content immersed and implicit in the materials designed by the teacher, for achieving that a disruptive and anomalous activity arises.

2.5 Communication

The communication moment is designed to show an example of Constructive alignment. This process uses communication as a cross-sectional ability to be integrated into the curriculum. Constructive alignment involves answering fundamental questions for curriculum planning and in particular the design of the courses responsible for developing and evaluating the skill that has been integrated into the curriculum: 1. What should students know or be able to do as a result of the course? 2. What activities are appropriate for students to achieve the expected learning outcomes? and 3. How can students demonstrate that they have achieved learning outcomes?

The moment itself responds to this logic. This is how two activities are proposed, in the first, an awareness-raising game creates a reflection around the need for clarity, accuracy, and formality that requires written communication in technical engineering contexts. The second activity is focused on the evaluation methods, which allow the feedback and the robust evaluation of learning. For the case of the course, the learning results are evaluated asking the teachers for the construction of a result of learning, and the exposition of an activity type anchors that it allows developing the skill (McKenzie & Egea 2017).

The first activity uses an active and collaborative learning experience. This activity introduces the concept of anchor activity, which can be used as a reflection on future learning activities, taking up the learnings that this anchor activity generated. For our case, the skill that must be "anchored" is written communication, as a fundamental element in the development of engineering solutions to such an extent that standardized technical languages have been generated, and measurement systems that allow the symbolic communication for the universal understanding of its concepts.

The activity involves a group exercise of four people who must model figures with clay. At first, the image of a model that participants must replicate is presented. At the time, each group must write instructions on how to build their model, using only technical language, without using explicit words describing the figure to be constructed. In a second stage, the built instructions are exchanged with other groups, who must build the new model from those instructions. In the end, the two models are compared, and a reflection is made of the differences and the origin of them, finding in general faults in the communication. Figure 5 shows the comparisons between the models made from the image and from the written instructions.

Figure 5: a) Good written communication and b) Limited written communication

About expected learning outcomes, at the end of the Communication moment, teachers will be able to: Plan activities oriented to the integration of curriculum competences using active and collaborative learning. Design anchor-like activities that allow primary conceptualization of disciplinary competences or the development of skills. And propose teaching methods for the development of written communication skills, creativity, innovation, and co-design. The communication moment answers all the question of constructive alignment, which is focused on the intentionality of the module and the active learning experience associated with the development of the skill.

2.6 Transformation

This moment focuses on curricular transformation, the importance of the coherence between the curricular design and curricular development. Thus, Transformation considers two workshops, in which teachers can construct learning experiences by using problems and projects. In the first Workshop, teachers discuss the values and purposes of the institutional mission as a start point for formulating the intended learning outcomes of programs, which must align with the University identity. Moreover, they analyse their roles and students' roles, (see Figure 6) and define, in a general way, the main abilities, competencies, and values that the education process should promote.

Figure 6. Activity to analyse the teacher and student's role according to University mission

The second workshop devotes to show the challenges and advantages to apply student-centred approaches. In this workshop, facilitators promote the use of PBL as an educational approach. The main intention is to analyse different possibilities that emerge when the curriculum design starts from intended learning outcomes (ILO) instead of academic objectives. In the same sense of previous moments, Transformation results as an exemplarity scenario that integrates previous abilities and knowledge to formulate new alternatives of teaching and learning.

Teachers, working in teams, design a PBL intervention for a specific ILO aligning at least five elements: 1) the definition of a Problem as the trigger of the learning process, this problem cannot be exactly a research problem. It can be an impulse, question, worry, or concern, something that motivates students to learn and invites them to reflect and think. 2) The planning of a project, where teachers carry out an in-depth discussion of the contents, which may not strictly follow up the syllabus, but must attend the requirements of the problem-solving process (project stages). 3) The grouping strategy, taking into account that PBL approach recommends making up the student teams before starting the course, defining a criterion for this task is essential; criteria as a randomly making up, or grade-point averages of students can help in the group formation. 4) The planning of Tutoring sessions and learning activities to support the development of the project; at this point, teachers as designers must define aspects like lectures, active learning activities, lab practices, and support resources, among others. Tutoring and facilitation must be an active part of academic experiences. 5) The design of student assessment, which should be consistent with the course objectives, content, learning activities, and learning outcomes. Finally, 6) the selection of facilities, where teachers are encouraged to choose support resources, and spaces (labs, classrooms, maker spaces, library, etc.) according to learning activities, taking advantage of physical resources available at the university and including other resources such as simulators, software, free online applications, etc. Teachers must consider all elements into their PBL intervention to guarantee a successful application.

Many educational alternatives have emerged of this activity, new teaching activities, new courses, modules that joint parts of other courses in a novel way and even, a new offer of elective courses. The most important result of this moment has been the awareness about the need to change engineering curricula and to work collectively to achieve it. This moment is only a brief introduction to curricular transformation; other advance training programs devote to this topic, there, teachers deal in-depth issues like the management of the change, PBL in the organization, and other approaches for engineering education (e.g., CDIO).

3 Participating observations

This section presents some reflection and observation made by facilitators who oriented the experiences in the teacher training program. These observations can be summarized in the following issues:

Motivation: Researchers observed that participants arrive with expectations, desires, and emotions to find something new that helps for strengthening their teaching practices. Some of them look shy, nervous and with uncertainty, this provokes that in the firsts workshops on self-recognition, they do not socialize the results easily to other participants and therefore, they are more comfortable with the individual reflection. Later, in the recognition workshops, considering that focuses on their students they are more confident to express their opinions, generating great complicity for collaborative work. They analyse their classroom experience and share their expectations, wishes, fears, which helps them to create working links and recognize their limitations and potentialities.

Scenarios: the scenario in which the workshop o training activity is developed, also determine an important issue in the training execution. Teachers enjoy working on topics or with elements that are little common in their day to day. To include LEGO blocks, colour clay, colour paper sheets, and tasks like modelling, cutting, writing, reading, building, among others, as a part of the scenario promote the generation of ideas and emotions, and improve communication. For example, the use of LEGO blocks as a tool for 3D communication engages teachers to express their opinions about their roles in the learning process.

Facilitation: The diversity of activities that exemplifies the facilitation process, as well as the participation of different knowledge fields, the inclusion of novel tools, and the workshop execution that devotes to encourage self-management, help participants to understand the importance of the new roles in the learning process.

4 Concluding remarks

Encouraging the curricular transformation in engineering education implies finding alternatives for engaging teachers in novel strategies centred on students' work. It is difficult to find these alternatives if teachers are no part of the change through experiential activities, in which they have the opportunity to feel, think and act as students, evaluating the advantages and limitations of the educational approaches. For the last reason, researchers propose a novel training program, where teachers become students again, enhancing their transversal competencies, especially, collaborative work and communication for consolidating as a team that leads new strategies, perspectives and educational frameworks that promote the change.

The learning space has become an essential tool in this change, taking into account that all moments considered in the training program take as scenario ALC, learning activities result in exemplarity experiences that show not only the use of novel learning activities but also the importance of the place in which they are carried out. In other words, new learning activities imply new learning scenarios, and new learning places demand new ways to teach. In the same sense, this paper, in an exemplarity way, also is a learning experience; the reader can note that each moment provokes different sensations and have different styles that derive from its purpose and nature.

All proposed moments in the training program encourage the change, both the curricular transformation and attitude change at seeking to evaluate new perspectives of teaching, which teachers have the responsibility to lead. Researchers propose these four moments, Interpretation, Disruption, Communication, and transformation, as triggers to act in a different way to what that we use to.

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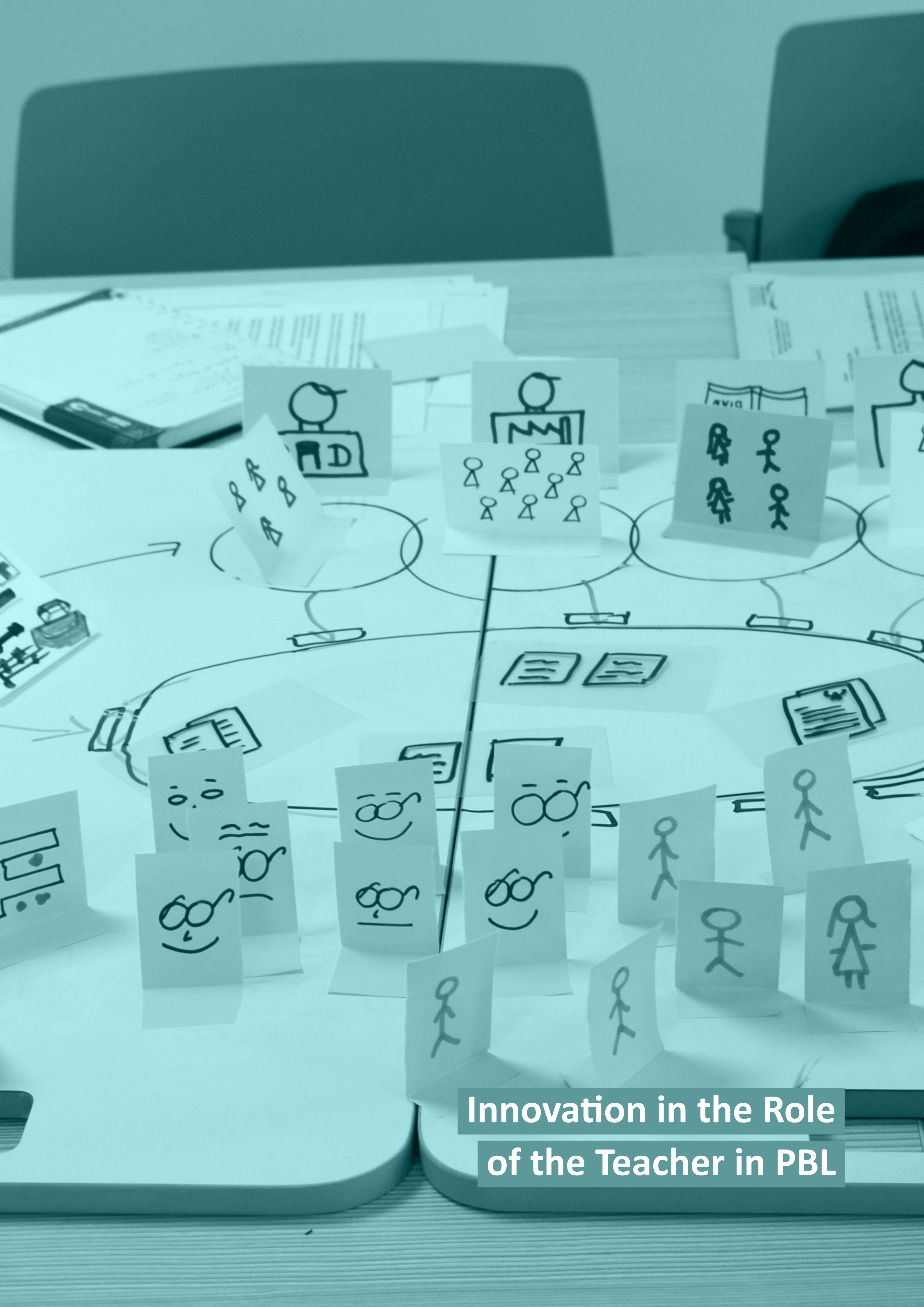

Innovation in the Role of the Teacher in PBL

Backwards Design, Standards-based Grading, and Scaffolding in the PBL classroom

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Abstract

How can an instructor navigate the tensions between a Problem-Based Learning approach and the principles of backward design (Wiggins and McTigh 2005)? Writing a good PBL problem often involves clarifying a set of learning outcomes, but student groups often take open PBL exercises into creative directions that may deviate from those intended outcomes. Part of the excitement of PBL, from an instructor's perspective, is letting students freely investigate and solve a problem; it involves giving them autonomy to explore creative solutions. But instructors also need to ensure that students achieve all learning objectives while letting them explore these open avenues of inquiry. In this paper I will show how standards-based grading and scaffolding are helpful tools for instructors to use in navigating these tensions.

Standards-based grading (SBG) is a flexible system of record keeping that allows an instructor to assign individual grades to each course outcome or standard (as opposed to combining them in more traditional grading systems). As Marzano (2010) and others have shown, this breakdown of an assignment, with grades given for each course outcome, allows students to clearly see how they met the goals of the assignment. Thinking through outcomes in relation to a PBL assignment can provide clear guidelines for students and ensure that instructional goals are being met and standards can be written to encourage creativity and exploration.

Creating variations of a problem and inserting or removing scaffolding is another way for instructors to help students focus on learning outcomes in PBL contexts (especially in a short time frame). Scaffolding can be employed dynamically, by either an instructor or a peer tutor, and can function as guardrails as groups wrestle with how to solve a problem. Together, scaffolding and SBG ensure that problems are meeting course objectives, groups are exploring creative solutions, and the assessment standards are clarified for students and instructors.

Keywords: backwards design, scaffolding, outcomes, standards-based grading

Type of contribution: PBL best Practice

1 Introduction

For many instructors who use Problem-based learning (PBL), one of the most important parts of planning an activity involves finding good “hooks,” or ways to present a problem to students to get them interested in a particular topic. Focusing on this part of a PBL problem is often time well spent, since engaging PBL modules often grab students’ attention and leverage preexisting knowledge and interest; these “hooks” foster motivation and self-driven learning. Yet, this focus on the beginning stages of an activity contrasts with the backward design approach to course planning. Wiggins and McTigh’s (2005) *Understanding by Design* framework begins with the end goals in mind; it then works backwards to create assessments and classroom activities that prepare students to meet the set of learning objectives. PBL teachers certainly have learning outcomes in mind for a given problem (and surely review them after students finish an assignment), yet one of the joys of teaching with PBL is allowing students enough flexibility to explore varied solutions and work in unexpected directions. Giving students space for this kind of creativity can be difficult to capture when using a backwards design approach. In this paper, I will show how standards-based grading and scaffolding are effective tools that allow instructors to mediate between these competing approaches to course design.

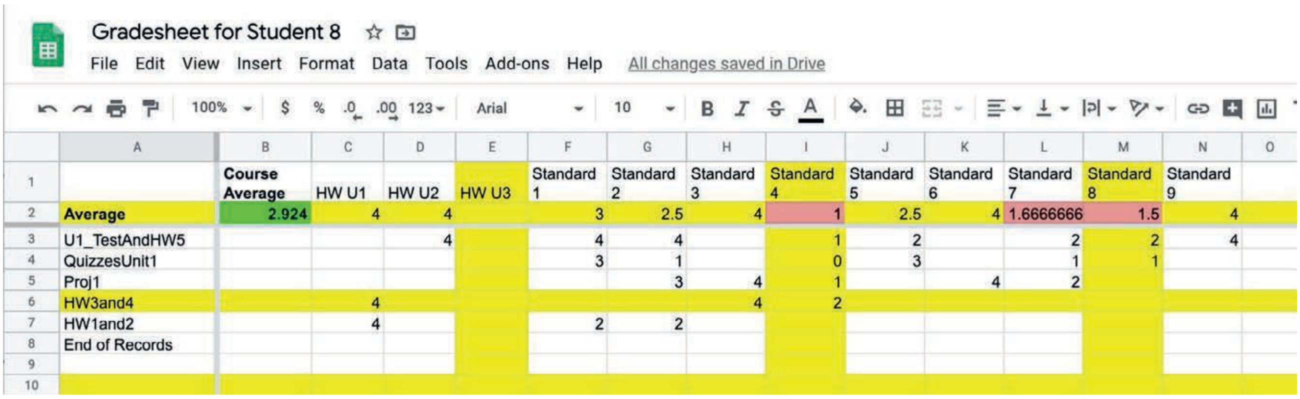
2 Standards-based grading

Standards-based grading (or SBG, also known as outcomes-based or criteria-referenced grading) is a system of record keeping that is organized around course outcomes instead of assessment type. Unlike more traditional grading systems that record grades based on the kind of assessment (e.g., homework, quizzes, projects, or tests), standards-based grading breaks down each assessment into the relevant course outcomes and assigns a grade for each outcome. In this system, a homework assignment might produce multiple scores depending on which course outcomes were relevant; a unit test would provide a series of grades instead of a single average. Those familiar with rubrics will find many similarities with the notable difference that the categories on the rubric do not sum together to create one final grade for the assignment. A physics problem, for example, might produce different grades for each of the following outcomes: using the proper formula(s), assigning variables and appropriate units, calculating the result, and drawing logical conclusions. Proponents of SBG often incorporate a number of progressive educational philosophies something that Schimmer (2016) calls the *standards-based mindset*. While I am generally inclined towards many of these ideas, I will focus on the core elements of SBG that allow for the widest possible adaptation and adoption.

2.1 Student perspective

SBG offers significant advantages from a student perspective (particularly for STEM courses, see Carberry, et al. 2012). Grades returned to students are much more informative as they are delineated by course standards; students can clearly see what outcomes they met and those that require more attention. This not only helps students have a clearer picture about how they performed on any given assignment, but also clarifies what learning goals were relevant to that assignment (which can sometimes seem obscure).

Beyond the level of the assignment, students can also see how they are doing in a class according to the learning outcomes of the course. Figure 1 shows an example of what a student gradesheet can look like. In this figure, each standard is listed as a column (F–N) and graded on a 1–4 numerical scale, where 4 is the highest grade and indicates mastery of a given outcome (SBG is also compatible with other systems, see below). The standards of the course are listed as columns across the top and each assessment is listed as a separate row. Scores for each outcome are averaged in row 2, giving the student an overall picture of how they are doing in relation to that outcome. Finally, these average scores are then averaged together for the student’s course average in cell B2 (highlighted in green).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		Course Average	HW U1	HW U2	HW U3	Standard 1	Standard 2	Standard 3	Standard 4	Standard 5	Standard 6	Standard 7	Standard 8	Standard 9	
2	Average	2.924	4	4		3	2.5	4	1	2.5	4	1.6666666	1.5	4	
3	U1_TestAndHW5			4		4	4		1	2		2	2	4	
4	QuizzesUnit1					3	1		0	3		1	1		
5	Proj1						3	4	1		4	2			
6	HW3and4		4					4	2						
7	HW1and2		4			2	2								
8	End of Records														
9															
10															

Figure 1: SBG Gradebook, Student View

An SBG gradebook allows students to quickly see what outcomes they are doing well on and those that need more attention. In Figure 1, Student 8 can quickly see that they need to give attention to Standards 4, 7, and 8 (conditional formatting on the sheet, such as highlighting any score below a 2.0 in row 2, can help alert students to these low scores—those scores are highlighted in red in the figure). At the same time, students can recognize how they are doing in the class as a whole (B2, the overall average), and also see which standards they have mastered (Standards 3, 6, and 9 in this example). While this new gradebook does take some getting used to, once students understand how to interpret their scores, it can be very informative for them to assess their progress in a course.

Most helpfully, the gradebook lets them see if they are not doing well in a particular standard; they can then focus their attention and study time accordingly. In a typical percentage system, two students may have gotten a 75% on a homework assignment, but had completely different problems that lowered their grades (for example, one might have calculation errors, while the other might have incorrect modelling or faulty interpretations of the data). The 75% does not tell the students what they need to study or practice in order to improve. In an SBG system, each student would see their scores divided by outcome, and having each standard delineated allows for each student to see what skills or topics they need to address.

2.2 Instructor perspective

While it admittedly takes some effort to adopt, standards-based grading holds many advantages from an instructor's perspective (see Knight and Cooper 2019). Most significantly, grading can be done more quickly since the grades communicate more information and so a grader does not need to provide as many comments. Switching to standards-based grading can also solve one of the fundamental paradoxes of grading with point systems or percentages: the time a student spends on an assignment is *inversely* proportional to the amount of time it takes an instructor to grade it (summing up the points takes a lot of time). In an SBG system, the instructor can quickly assign grades to any outcomes that were not adequately addressed without having to count up points or percentages.

Just as students could see the breakdown of skills in their gradesheets, this richness of information is passed on to instructor. Figure 2 shows a class gradebook. The first tab, (shown along the bottom of the figure) labelled "Average," shows the course averages for each student according to each outcome (this is row 2 from each student sheet; cf., Figure 1). Each subsequent tab represents a course assignment (a Unit test and homework assignment, followed by quizzes, a project, and other homework in this example). The "Average" tab gives an instructor a quick snapshot overview of how the class is doing as a whole and allows an instructor to analyse the data on how students are doing. This "Average" tab shows the average grades for each standard, and also the average score of the class by standard (the averages of the standards are shown in row 21). Since grades are organized by standard, an instructor can quickly see which outcomes are giving students the most trouble and focus class time on those standards (e.g., Standard 4 has the lowest average score in Figure 2). Students' overall grade averages are shown in column C, and C21 gives the overall class average. A standards-based gradebook shows an instructor how each individual student and the whole class is doing, and the breakdown by standard allows instructors to tailor advice and coaching to where students most need it. While this certainly doesn't serve as a panacea to solving student problems (which often has to be done individually), it can provide a good measure of class trends.

SBG Master Spreadsheet Example

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Student Name	e-mail	Course Average	HW U1	HW U2	HW U3	Standard 1	Standard 2	Standard 3	Standard 4	Standard 5	Standard 6	Standard 7	Standard 8	Standard 9
2	Student 1	spam1@gmail.com	3.432	3.5	3		3.6666666	3.75	3.5	3	3	4	3.3333333	3	4
3	Student 2	spam2@gmail.com	3.034	3	2		3.3333333	3.375	4	3.5	2	3	3.6666666	3.5	2
4	Student 3	spam3@gmail.com	3.144	3.5	3		4	3.25	2	3	3.5	3	3.3333333	3	3
5	Student 4	spam4@gmail.com	3.47	4	3		3.6666666	3.25	3.5	3.25	4	4	3	3.5	3
6	Student 4	spam4@gmail.com	3.348	3.5	2		3.6666666	3.25	4	3.25	3	4	3.6666666	3.5	3
7	Student 6	spam6@gmail.com	2.977	4	3		2.3333333	3.75	2.5	2	2.5	4	3.6666666	2	3
8	Student 7	spam7@gmail.com	2.871	1	0		3.6666666	3.5	3.5	3.25	3.5	3	3.6666666	3.5	3
9	Student 8	spam8@gmail.com	2.924	4	4		3	2.5	4	1	2.5	4	1.6666666	1.5	4
10	Student 9	spam9@gmail.com	3.258	4	3		3.3333333	3.25	2.5	2.75	3.5	3	4	3.5	3
11	Student 10	spam10@gmail.com	3.333	4	2		3.6666666	4	3	3	2.5	4	4	3.5	3
12	Student 11	spam11@gmail.com	2.614	0	0		3.6666666	3	3	2.75	3	4	3.3333333	3	3
13	Student 12	spam12@gmail.com	3.348	4	2		3.6666666	2.25	3.5	3.25	3	4	3.6666666	3.5	4
14	Student 13	spam13@gmail.com	3.197	4	3		4	3.5	3	2.5	3.5	4	2.6666666	3	2
15	Student 14	spam14@gmail.com	3.265	4	3		3.3333333	3.25	2.5	2.5	3.5	4	3.3333333	3.5	3
16	Student 14	spam14@gmail.com	3.553	4	4		3.6666666	3	3.5	2.75	4	4	3.6666666	3.5	3
17	Student 16	spam16@gmail.com	3.22	3.5	0		4	3.25	3.5	3.5	3.5	3	3.6666666	3.5	4
18	Student 17	spam17@gmail.com	2.614	4	0		2.3333333	2.75	2	2.5	2	3	3.6666666	3.5	3
19	Student 18	spam18@gmail.com	3.277	3.5	3		3.3333333	3.625	3.5	2.75	4	3	3.3333333	3	3
20															
21			3.16	3.417	2.222		3.463	3.25	3.167	2.806	3.139	3.611	3.407	3.167	3.111
22															
23	number of outcomes:														
24															
25	13														
26															

Average | U1_TestAndHW5 | QuizzesUnit1 | Proj1 | HW3and4 | HW1and2 | End of Records

Figure 2: SBG Gradebook, Instructor View

As Marzano (2010) has shown, there are many ways of recording grades and determining the final score for a given standard. An instructor could average all of the scores from different assessments or weight more recent scores more heavily (e.g., the last grade is worth 70% and the previous two grades are averaged for 30%). The grading scale used can also translate into different letter grades depending on the class. In an upper level course that I teach using a 0–4 scale, a 2.25 is the bottom threshold for a "C-", and grades increase by .15 increments (e.g., a "B-" starts at 2.7, and "A-" begins at 3.15). In a lower-level course, I use the same 0–4 scale, but a "C-" begins at 2.85 and increases by .1 increments (e.g., 3.15 is a "B-" and 3.45 is an "A-"). This malleability allows an instructor to craft and refine the best system to reflect the challenge of the material and what students need to know in a given course. Once released from an assignment-framed grading practice, instructors are also free to incorporate grades for student-initiated projects that demonstrate their knowledge. A teacher could also conduct an informal assessment where students can demonstrate competence in regards to a given standard. While instructors should be careful that they are being fair to all students, such extra assignments or meetings could be an option extended to students with test anxiety or to students who miss an assessment.

2.3 Flexibility and metacognition

While the above discussion shows some of the advantages of using SBG in any classroom, this system offers specific advantages to instructors using PBL. Using a standards-based system in a PBL context encourages an instructor to map out all of the relevant outcomes in relation to a problem including some of the general or "soft skills" that are often a part of PBL activities. Communicating effectively, being a good teammate, creating action plans during the problem-solving process, and analysing resources are all common elements of PBL exercises that are not normally captured by the content objectives of a course. As an aside, it is interesting to note that many of these non-content related skills are often specified as learning goals at the program or general education level and specifying them as standards can connect up to these larger curricular or institutional goals.

Turning back to the level of the problem, an instructor could include standards like: finding a creative solution to the problem, integrating topics/interests of the team, or relying on interdisciplinary perspectives. These categories can be suggestive as long as they encourage the desired results. In SBG, instructors can create any standard that they feel can focus student attention appropriately and are only limited by what they can effectively put into words to describe the outcome. Standards can be created to capture any learning goal that an instructor can imagine and effectively communicate (although proponents of SBG would caution against what has been called “hodgepodge grading,” see Cross and Frary 1999).

This also means that instructors arguably should create specific standards that ask students to engage in self-reflection and metacognition, as is often done to wrap up a PBL activity. Numerous studies (e.g., Agarwal and Bain 2019) have shown the value of getting students to reflect upon their learning: it leads to better assessment scores and retention. Setting up a standard for this could be based on a simple rubric for completion with some suggestions for the level of depth in student responses.

2.4 Evaluation and Feedback

Even though standards-based grading allows an instructor to specify whatever learning outcomes they choose for a course, it does not inhibit an instructor from using formative feedback with students. The standards in a course should serve the learning goals that an instructor prioritizes, not limit what an instructor can do. Although some scholars caution that standards should be limited to content mastery (e.g., Marzano 2010), instructors sometimes want to value non-content goals and reflect those values into their grading systems, especially in a PBL context. SBG can accommodate those kinds of standards as well. For example, an instructor could have students electronically submit a short assignment at the beginning of class (e.g., take a picture and submit on LMS) before going over the assignment and discussing solutions in class. The instructor could then choose to either give students a grade based on how much of the assignment they completed (instead of the quality or their solutions), or not. I have often used this sort of “homework completion” category in my courses. Since it is only one standard it does not impact students’ grades significantly, but it is enough that students consistently try to complete the exercises, even if they find the assignment challenging. Alternatively, the instructor could choose not to grade the assignment (perhaps due to time constraints). Whether for a grade or not, this approach allows students to get timely feedback on their work without penalizing for a lack of subject mastery. SBG is fully compatible with these and other kinds of formative grading approaches; it does not lock an instructor into a summative assessment box.

2.5 Criteria-referenced vs. norm-referenced grading

Another advantage that SBG can have in a classroom is shifting grading practices from being norm-referenced to criteria-referenced, which can dramatically increase student cooperation and peer support. In norm-referenced grading (also known as grading on a curve), instructors determine a priori that a certain percentage of students will get “A”s, “B”s, “C”s, and lower grades. Assessment results are then stratified to meet the predetermined statistical breakdown. This may mean that students who performed poorly on an assessment may still get a “B” or a “C” because of how badly the class did as a whole (e.g., I have heard of a student getting an “A” despite earning a 57% on an exam). In this type of grading environment, students are pitted against each other. They do not necessarily have to score well on the test and master the content, they just have to do better than their peers to get a good grade. This kind of competitive mindset is antithetical to group work and cooperation, and certainly works against developing successful teams in a PBL context.

In contrast, standards-based grading is criterion-referenced which means that students' grades are based solely on how they demonstrate mastery of a learning goal without reference to the performance of other students. It is possible that all students in a class could earn the highest score on a given standard, and instructors do not alter a students' scores based on how the class did overall. While an instructor's attitudes and directions can play a large role in determining a class environment, criterion-referenced grading can encourage students to help each other and collaborate together to meet goals since they are not competing for grades. Instructors can suggest (and even reward) informal peer-learning activities and supplemental resources that students can provide for each other. Standards can be written to promote such activities and if carefully worded, they should not inhibit them. When working well, standards provide challenging but also realistic and achievable goals for students. In an SBG context if the class does not meet over half of the learning objectives on an exam, that often indicates a problem with: the exam questions, the difficulty of the learning goals set, the class preparation, or some combination of these or other factors.

Shifting to SBG can be especially valuable to instructors who have taught a course multiple times since it forces them to clarify and prioritize the learning outcomes of the course. The process of clarification can be not only based off of a curricular perspective on what the course should accomplish, but also incorporate the hands-on experience of what students are capable of achieving with the course. Veteran instructors can have a perspective of what each activity is meant to accomplish and how effective the assignment has been in meeting those goals historically. Once instructors have clarified and prioritized the standards for a given course and the set of PBL activities (including non-content objectives), they can better manipulate the problem and also choose whether to include scaffolding to help focus on those standards.

3 Variations and scaffolding

Almost any PBL problem can be adjusted to create a wide array of variations. Changing the fundamental assumptions of a problem (e.g., building a structure in the desert instead of Antarctica, examining a newly-discovered species instead of a familiar microbe), or the modality that students will use to present a solution (e.g., a paper, a presentation, or a video) can radically transform how students approach, work through, and learn from a PBL activity. But of these seemingly vast number of variations, which is the best fit for a given class? Having a clear idea of outcomes, a requirement of a standards-based grading scheme, can help instructors decide between these different possibilities. Having clear goals in mind helps an instructor frame the problem and determine how best to present it to students. It can also help instructors focus an activity to target those standards by providing or removing scaffolding (van de Pol, et al. 2010).

Scaffolding is instructional support that helps students successfully complete an activity in an efficient way. Making students aware of a resource, providing a conversion table, or suggesting a database are all ways that instructors can scaffold a problem to more efficiently target learning outcomes and ensure student success. There are times when instructors want students to wrestle with the avalanche of information on a given topic; a frequent outcome for PBL problems is for students to determine appropriate and relevant resources. That said, there may be other times when instructors can only devote a short amount of class time to a given problem and sometimes instructors choose to skip a PBL activity because of insufficient time. In those cases, scaffolding can provide a solution by streamlining the activity to better address the learning outcomes. Perhaps an instructor wants students to concentrate their work on creative solutions instead of observation and data collection. Providing the initial data would be a way to scaffold a problem to promote the most important and relevant learning outcomes.

Scaffolding can also be employed dynamically, by either an instructor or a peer tutor, and can function as guardrails as groups wrestle with how to solve a problem (see Schmidt et al 2011). While some discussion about how a group will work to solve a problem is often desirable, instructors and/or peer tutors can steer conversations in a particular direction if the group is not focusing on the overall goals of the exercise. If peer tutors are used, they should be reminded of the learning goals of the exercise, so that they do not inadvertently undermine one of these goals as they help guide the groups through the problem. Since there will only be a few standards associated with each assignment, the tutors should be clear on what kinds of help would shortcut and diminish the group's learning. In terms of helping, Hmelo-Silver and Barrows (2008) note that sometimes even a few pointed questions can help students organize information in productive ways to move forward on a problem. Socratic questioning should be a frequently used tool in tutoring situations and the clear goals provided by a SBG approach make that much easier andefficient.

One of the more effective ways to deploy scaffolding is through scenarios, or written out descriptions where the student groups occupy roles or play characters in a story. These scenarios allow the instructor to add or subtract elements from the story line to adjust the level of scaffolding in a problem. It also allows the instructor to position the students as occupying particular roles in the situation—these details help instructors focus students' attention on the learning goals of the exercise while still giving them flexibility to work on the problem in various ways. As opposed to starting a problem from scratch, for example, students can be put in the role of taking over the project of a colleague who was deployed elsewhere. Their previous colleague will have completed just enough of the work so that students can focus on the aspects of the problem that are relevant to whichever standards the instructor has prioritized. Scaffolding a problem can vault students into the level of productive struggle on the most important course standards (Barlow, et al. 2018).

Scaffolding can also be an invaluable resource when instructors are teaching in asynchronous and online environments where students do not have the luxury of meeting face-to-face during class time. Collaborative Google documents, Zoom meetings, and Slack-type discussion boards are all wonderful resources that can be used in asynchronous class settings to facilitate communication about a problem. In these contexts, scaffolding can provide a guided pathway for groups to wrestle with the essential outcomes of an exercise. While the online environment poses many challenges to this kind of pedagogy, scaffolding provides ways of engaging some of the most important features of PBL exercises.

4 Advice for Implementation

Whether used dynamically or statically in the prompt of a problem, techniques for scaffolding are similar and closely aligned with many current teaching practices. The adoption of a standards-based grading approach on the other hand, requires a number of large and small changes that can pull instructors and students into unfamiliar territory. I will address some common issues of implementation (for further resources, see Guskey 2009, and Peters and Buckmiller 2014).

4.1 Grading and weighting

Instructors adopting an SBG approach will likely want to consider some of the aspects of grading that are often taken for granted. For example, grading scales do not need to use a 1–100% percentage system; instead, instructors can develop different scales to measure students' achievement and represent that level of accomplishment. A 0–4 scale is commonly used and will often provide enough discrimination about how students are meeting a particular standard (0–5 or 0–10 are also possibilities). An instructor could also use Pass/Not Pass scales for standards (as in specifications grading), or even the familiar 0–100% scale if they wanted. Using a Pass/Not Pass scale is especially useful if certain outcomes are prerequisites for later courses in a given curriculum. Instructors can set up these standards so that a student cannot pass the class if they have not met these benchmarks. In all of these cases, giving students a rubric can help clarify how their performance will translate into a grade.

Beyond grades assigned, instructors can also have different weighting schemes in determining how the standards contribute to the final grade. Instructors can stress the importance of some standards over others, or even specify that students must pass certain standards in order to pass a course as mentioned above. While variable weighting systems can be confusing for students, instructors can also mix different systems. It is possible to make certain standards Pass/Fail and then use a numerical score for the other outcomes in the same course. The author has used such a system and found that it works well (e.g., using Pass/Not Pass system for Unit 1 standards and then using a 0–4 scale for Units 2 and 3).

In a PBL context, delineating standards that target general team and communication skills (such as the ability to work in a group and produce cogent written communications) sends a strong signal to students that these are not by-products of a strange pedagogy, but actual outcomes that they need to achieve. It is useful to point out that in future employment it is not enough to get the correct answers; it matters quite a bit whether one can work productively in a group setting and communicate one's ideas effectively.

4.2 Technical challenges

Instructors wishing to implement a standards-based grading approach can find course management software that will help them with record keeping, but such programs can often be costly. In addition to cost, another disadvantage to these systems is that they often do not allow for much flexibility in terms of mixing grade types for each standard (e.g., having pass/not pass standards, using letter grades, or using a numeric scale). Nor do many of these programs allow flexibility in weighting the standards differently. In contrast to these options, the author has developed a free solution that relies on Google Sheets and Google App scripts. This implementation allows instructors to oversee all factors of grading; a class can have mixed types of assignments and the instructor determines how a grade is calculated. Since one can design formulas based on their desired weighting schemes, instructors have precise control over how grades are determined and presented to students. Furthermore, the scripts and set-up are open-access and freely available on Github for other users to use and/or adapt for their own purposes. If an institution uses Google Apps already, it should be quite feasible to adopt this solution.

4.3 Communicating with Students and Rubrics

An important aspect of successfully implementing an SBG system is presenting and explaining it to the students, especially if this can be done over multiple courses in a curriculum. As Robert Talbert (2015) has noted, SBG systems are more complicated and can easily overwhelm students who do not understand how their grades are being computed. At the beginning of the semester and when you hand back the first assessment, it is often helpful to take time to explain how students should read and react to the series of grades they receive on an assignment. It is also helpful to walk through how they can understand their gradesheet once the first grades show up there (see Figure 1), especially if students are accustomed to the traditional 1–100% system. It is useful to stress the advantages of this system (e.g., "it helps you see what you need to study"), as students can often react negatively to systems that are unfamiliar. Overall, the system should be transparent to students and you should walk them through examples of how to understand their grades and how you would hope they would act based on this information.

One way to lessen the learning curve for students is to distribute rubrics for assignments before the due date so students can make sure that they are meeting your expectations. In a PBL context, it is often desirable to withhold a rubric to allow groups to wrestle with a problem without that structure. That said, after these initial stages and as students are finishing up their work, rubrics can offer a helpful guide for students to complete their work.

On the assignment level, one advantage of the SBG approach is that since the series of grades communicates information about the how students performed, there is less of a need for instructors to write copious comments and annotations to projects. While some comments are often helpful, the grades themselves already point out the strengths and weaknesses to students and can focus their attention on the course standards they need to improve. As an alternative to handing out rubrics before an assignment is due, instructors may choose to provide rubrics when they return the submission as this will help student interpret their work. Rubrics used in this way can also serve as a guide for revisions and resubmissions.

4.4 Reassessment and Logistics

One philosophy related to an SBG approach is that students should have grades that reflect their current understanding of an idea, not necessarily how they performed on a past assessment (Marzano and Heflebower 2011). Adopting this idea lets instructors accommodate different learning preferences and speeds (while also embracing principles of Universal Design for Learning, see Tobin and Behling 2018). In a PBL context, letting student groups resubmit out of class work, such as projects, can help alleviate some of the stress when these assignments count for a large portion of the grade. Often in these contexts, it is useful to ask students to reflect on their initial work and to require reflection reports with any resubmission. Allowing make-ups can also encourage students to keep trying in a course since it is never "too late" to turn their grades around. As Schimmer (2016) notes, grades communicate quite a bit to students and can easily deflate student confidence if they are unchangeable. On the other hand, having a generous re-take policy can create practical and logistical challenges for instructors; these make-ups can become time consuming. Furthermore, some instructors worry that their students do not take initial assessments that seriously when they know that they can do them again later.

There are some strategies that can mitigate these challenges to a make-up policy. Putting limits on the number of makeups that students can submit (e.g., a group can only resubmit a PBL once), as well as requiring resubmissions to be done within a week or two from whenever the project is returned can help instructors manage workload and not become overwhelmed by grading. For in-class assessments, having two to three scheduled days (either in or outside of normal class time) can help manage these kinds of reassessments.

4.5 Creativity and Flexible Standards

Once an instructor switches to a standards-based grading format, it becomes much easier to reward groups when they go beyond the expectations of a project (whether through extra work or optional components). For example, one way to reward a group that comes up with a creative solution in a project is to have a standard titled "creative solutions" (this could be done at the project, Unit, or whole course level depending on how much you want it to impact the students' overall grades). Then depending on how groups perform on a given project, you can give those groups who come up with creative solutions the highest score on your scale for that standard. The other groups would not get a score in that category for that project (and the lack of a score would not impact their grade positively or negatively). Using this approach, instructors can assign positive grades on outcomes that they encourage but do not require. Having optional standards for outcomes like "creative solutions," gives high-functioning groups something to strive for in addition to fulfilling the minimum requirements of a project. It allows flexibility since it does not necessitate that all groups come up with novel results, but it does reward groups that are able to do so. This flexibility also makes SBG quite adaptable to both higher and lower level courses (i.e., both introductory and advanced levels). As mentioned previously, since instructors often have tremendous freedom when writing or adapting the standards, they are only limited by what they can capture in words.

4.6 Student reactions

As in many changes that are introduced to our classes, student reactions to SBG tend to be mixed. For many students, knowing that it is possible to reassess can greatly reduce their test anxiety and assessment-related stress. Many students will appreciate this benefit as a welcome trade-off for their grade being "more complicated." The strongest negative reactions often come from students who perform generally well but have un-even skill levels. In some of these cases, their grades in previous courses may have masked their deficiencies (since their strengths could have compensated and boosted their overall grade). For students in this situation, it can be uncomfortable to see that they are doing poorly on some standards, and they can feel frustrated that their "good work" on other standards is not being recognized enough. With these students, it is important to stress the learning goals of the course and how the standards operationalize those goals. It can also be helpful to point out that low scores are not permanent and that they represent areas that need attention and focus before the next reassessment. While few students enjoy hearing that they have to do more work or study more, the ability to change a grade is one that they should embrace.

4.7 Initial implementation

Students are often skeptical when faced with new approaches to grading. Pointing out some of the advantages to this system from a student perspective (re-takes and improving previous scores) can often convince students that an instructor is prioritizing their learning and achievement. It is helpful to emphasize multiple times that your priorities are the learning goals of the course. If a student has met a goal, then they should be able to demonstrate that learning to you. That said, there are many pitfalls that a new instructor adopting this system could encounter.

Similar to implementing any new system, clarity and communication with students is key. Instructors should make sure that they are comfortable with the grade distribution workflow (such as the Google sheets solution discussed above) so that students can easily see how they are doing in the course. Feedback is also most effective when it is received promptly, and new systems are a likely culprit in students' minds if there are delays in returning work (this can become a sticking point with any new grading system that is introduced; e.g., "it takes too long to grade things in the new system"). Letting students know about how long something will take to grade when they submit an assignment can help set student expectations.

Depending on how widely SBG will be adopted throughout the curriculum, it can be beneficial to introduce the grading system in earlier courses so that students become familiar with the approach as they learn foundational material. Introducing a new grading approach in upper level classes, where content is typically more challenging, can cause some students to blame the grading system instead of recognizing the difficulty of the material. Once students have experienced this kind of grading in earlier classes, they are much more comfortable when encountering the system in upper level courses.

In addition to ensuring good communication channels with students, it is worth meeting with and discussing the new grading system with department chairs, deans, and/or other supervisors. Peters, et al (2017) identified a lack of community support and understanding as one of the biggest obstacles to implementing SBG (see also Frankin, et al. 2016). Getting support from upper administration for SBG should be an important factor in deciding on when and how to implement the new system as some students could blame the new system for their poor performance. I have heard an unfortunate story from a colleague who said that while they felt the system was working well and raising the standard of student work, some of their students went directly to supervisors to complain that the new system was not fair and they were not doing well because of it. My colleague described the situation as "pedagogically effective but a public relations nightmare." Preemptively making your case to chairs and supervisors about how SBG works and how student learning is prioritized in this approach can help prepare them to ask pertinent questions when faced with student accusations of unfairness (e.g., "how have you tried to improve and reassess your low scores?", "is it the grading system or the material that is causing difficulties?").

5 Conclusion

In combination, standards-based grading and scaffolding can ensure that students are meeting course objectives in a problem-based learning environment, while allowing instructors to use backward design principles in creating outcomes, assessments, and activities. SBG helps instructors clarify the outcomes associated with a given assignment, including those critical thinking and group work skills that are frequently overlooked (in favour of content objectives). At the same time, providing variations on problems and deploying scaffolding can ensure that student groups are working towards and focused on the most important standards. By highlighting all aspects of the PBL process, instructors can help keep their students focused on the most important learning goals while also allowing room for creativity and exploration.

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A Problem-Based Approach to Teaching a Course in Engineering Mechanics

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"I never teach my pupils, I only attempt to provide
the conditions in which they can learn."
Albert Einstein

Abstract

Problem-Based Learning (PBL) can be defined as a learning environment where problems drive the learning. A teaching session begins with a problem to be solved, in such a way that students need to gain new knowledge before they can solve the problem. This paper discusses the application of PBL to teaching an introductory course in engineering mechanics at Aalborg University, Copenhagen, Denmark for first semester students enrolled in the program "Sustainable Design". We pose realistic problems which do not necessarily have a single correct solution. Project work in groups also presents itself as a supplement for conventional engineering education. The students themselves should interpret the problem posed, gather needed information, identify possible solutions, evaluate options and present conclusions. The paper also presents an initial assessment of the experiences gained from implementing PBL in the course. We conclude with a discussion of some issues in implementing PBL in engineering and mathematics courses.

Keywords: PBL, engineering mechanics, engineering mathematics, interdisciplinary

Type of contribution: PBL best practice

1 What is Problem-Based Learning?

In contrast to a traditional teacher-centred pedagogy, PBL is a learner-centred educational method, based on realistic problems encountered in the real world. These problems act as a stimulus for learning, integrating and organizing learned information in ways that will ensure its application to new, future problems. However, a point worth noting here is that a problem might not always be something practical that needs to be fixed; it could also be something that initiates the learning process for instance a description of a natural phenomenon (Graaff 2016). Dahl (2018) furthermore describes theoretical problems in PBL and she perceives these as anomalies in our understanding, explanations and theories about the world. PBL is based on a constructivist theoretical framework that is also applied in instructional models such as ""Inquiry-Based Learning" (IBL).

The term Problem-Based Learning was coined in 1969 when McMaster University in Canada introduced PBL into its medical school in an effort to provide a multidisciplinary approach to medical education and to promote problem solving to its graduates (Barrows & Tamblyn, 1980). PBL was soon adopted by many universities worldwide (Mills *et al.*, 2003). Educators and researchers are still showing increasing interest in PBL approaches that claim to stimulate the students' self-learning and to promote their communication skills. In a PBL teaching situation, problems are introduced at the beginning of the teaching unit, e.g. a lesson or a semester, before presenting the students with the relevant knowledge during the course. By actively engaging with the problem, students can develop skills around identifying the information they need and also the possible sources of that information. The goal is to enable them to relate what they are learning in class to their own experiences as well as to important issues in their world (Askhave *et al.,* 2015). Nowadays, internet technology brings with it a rapid explosion of easily accessible knowledge. Graduates are expected to be critical thinkers, problem solvers and systematic in their approach and possess lifelong learning skills. The interdisciplinary nature of real-life problems means that students need to be able to integrate knowledge and skills from several disciplines as well as have personal and communication skills to be an effective group member. "The knowledge which is valued in problem-based learning is that which can be used in context, rather than that which justifies the structure of particular disciplines" (Boud & Feletti, 2013, p. 16).

In PBL, an important task of the teacher is to initiate discussions in the class in order to enhance the students reasoning skills and encourage them to apply their previous experiences to a novel case, thus enabling them to identify areas of gaps in their knowledge and prepare them to new knowledge acquisition. Through PBL, students are gradually given more and more responsibility for their own learning and become increasingly independent of the teacher in their understanding (Barrows & Tamblyn, 1980). One should also note that PBL is not merely preparing problems for the students to solve in the class, "but also about creating opportunities for the students to construct knowledge through effective interactions and collaborative inquiry" (Tan, 2003, p. 22).

Instructional, fact-based learning may continue to be important for becoming an expert at anything. In fact, using fact-based videos from websites like YouTube and Kahn Academy would make it easy for instructors to flip their classrooms by allowing students to digest instructional content at their own time and pace. This can be a genuine opportunity for instructors since it frees up class time to offer a PBL approach and personalized coaching to students as they work on projects in the class

It should be emphasized that PBL is not to be confused with Project-Based Learning, even though both learning environments are similar in strategies. Project-based learning is a teaching method in which students acquire and apply knowledge and skills by working for an extended period of time to investigate and respond to an authentic and complex question or problem that is too large to be solved single-handed (Barge, 2010). Both problem-based and project-based learning are student-centred and "emphasize the learning process instead of the teaching process" (Kolmos, 1996).

This article shows one way to implement PBL in an engineering mechanics course, where mathematics, engineering science and communication skills are taught in an integrated fashion, using a course project that deals with the solution of real-world problems and serves as a learning context. However, no claim is made that PBL would generally work in every engineering or science discipline. In fact, the suitability of PBL for engineering is still subject to debate among educational researchers. For example, Perrenet *et al.* (2000, p. 349) reported that "findings from research on misconceptions suggest that PBL may not always lead to constructing the right knowledge", given that PBL is a constructivist theory of learning.

Moreover, as Mills *et al.* (2003) pointed out, one of the obstacles to full implementation of PBL in engineering "would require interest, cooperation and integration of faculty from at least the engineering, mathematics, science and business/management divisions of an institution." Another important issue in a PBL implementation across a whole engineering program is related to the hierarchical knowledge structure of mathematics and engineering compared with medicine, where PBL has been widely adopted (Feletti, 1993). This is perhaps the most fundamental hindrance for implementation of PBL through an entire engineering program, as opposed to within individual courses in the program. Constructivist methods, where students inquire problem/situations and assign a facilitator role to the teacher, can be quite challenging, and sometimes difficult, to implement. Maybe this could be one of the reasons why many teachers may either ignore the methods or, at best, pay lip service to them. In fact, many studies revealed that teachers and educational practitioners, who are mainly interested in the improvement of teaching, are quite sceptical and are not interested in theorization (Verstappen, 1991). This entitles that new energy and resources are needed in order to narrow the gap between the theory and practice in education.

2 The Course Project

The curriculum of "Sustainable Design" includes both semester projects and courses (Aalborg University, 2015), where the courses should presumably support the projects by providing the necessary engineering knowledge that could prove relevant in the semester projects. The course "Models, Mechanics and Materials" itself should include an introduction to statics and strength of materials as well as mathematical topics such as differential equations and linear algebra (Aalborg University, 2017). As PBL teachers, it is our responsibility to design teaching situations that provide guidance to tackle authentic situations and facilitate students' learning, in such a manner that the topics of the course are embedded within these teaching situations. The course project is therefore structured in a such a way that the fundamental topics in statics, strength of materials and engineering mathematics are covered, as required by the curriculum of the course. The textbook by Hibbeler (2019) is used throughout the course, together with hand-written notes, which are made accessible on Aalborg University learning platform, *Moodle*. The project in the course consists of three parts:

- Analysis and redesign of a swing (Figure 1).
- Analysis and redesign of a chandelier hanging from a ceiling (Figure 2).
- Modelling of a spring horse (Figure 3).

These parts are deliberately chosen in such a way that

- they are *related* to the first semester project of "Sustainable Design", where the students should design (or redesign) equipment for a playground for children. The students' designs should meet safety requirements and should include design calculations, and
- all the central topics of the course are represented in the questions asked in the project formulation.

Figure 1: The first part of the project

Figure 2: The second part

Figure 3: The third part

The project formulation is made accessible for the students in the very first lecture, where we gave an overview of the topics of the course. Each topic in the project was then introduced into the course lectures, such that as each major content of the course syllabus was covered, the students were asked to work in groups to complete the corresponding parts of the project. Each group had to submit progress reports periodically. This was useful in providing feedback to the students before they uploaded their final project reports to Moodle at the end of the semester.

A close look at the structure of the “Sustainable Design" program will reveal that product design constitutes a major part of it. The product designer is a problem solver who, given a problem or a need, applies such fields as physics, mathematics, hydraulics, electronics, metallurgy, strength of materials, dynamics, magnetism and acoustics in order to find a solution, namely, the new product (Tayal, 2013).

One aspect of product design is related to the modelling of a real-life design through simplified physical models that can be analysed using the fundamental engineering concepts, such as those in this introductory course in engineering mechanics. This aspect of modelling is rarely illustrated in engineering textbooks developed for such introductory courses, despite its importance. Although these textbooks contain at the end of each chapter plenty of problems that reinforce the concepts covered in the chapter, they usually do not discuss the relationships with the other topics covered elsewhere in the textbook. The course project can thus be regarded as an attempt to revitalize the modelling aspect in design and to illustrate the links between all the fundamental concepts of the course that perhaps can lead to a better understanding of the big picture. We, PBL teachers, have an important educational mission: To enable the students to apply seemingly isolated, theoretical results to genuine, real problems they did not meet before. This is where, we believe, “understanding" a method or an equation comes to an end. Only in that case, the “mission is accomplished". In our course, we always began the lectures with unstructured discussions of issues related to the course project. The students were then given comprehensive introductions to the topic(s) of the day and guided through a set of sample calculations on existing designs, as well be shown in the following section.

3 A Teaching Situation in Statics: An Example

To illustrate how we apply PBL in the course, a teaching situation in statics will be presented here. As mentioned in section 1, an important educational task of the instructor is the facilitation of class discussions in a PBL teaching situation. Thus, in introducing the topic “Statics", the starting point was the "girl on the swing" project (Figure 1). The class discussions were triggered by the question “what are the conditions to be satisfied so that the girl will be sitting still and does not move?" The “no force" condition emerged clearly from these discussions. The discussions then turned on the importance of giving “directions" to the forces exerted on the girl. This personalized knowledge about forces and equilibrium is transformed to a formal, precise knowledge by going through topics such as vectors, forces, free-body diagrams (FBD) and the conditions for equilibrium (Hibbeler, 2019):

$$\Sigma \vec{\boldsymbol{F}}=\mathbf{0} \qquad \text{and} \qquad \Sigma \overrightarrow{\boldsymbol{M}_0} = \mathbf{0}$$

As an illustration of the principles of statics, a sample problem was worked out in details in the class (Figure 4)

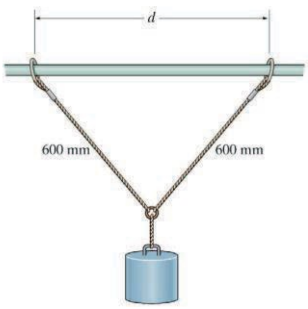

Figure 4: The example used to introduce statics

The problem was chosen to be “statistically" similar to the questions in the course project. The calculations and explanations were written with a stylus pen on a Wacom tablet (Figure 5), the purpose of which was to free the students from writing or taking pictures of the board, as the document was uploaded om Moodle at the end of the lesson. In a PBL situation, it is important to give the students time to reflect on the methods used and to ask questions, rather than spend time taking notes from the board. This strategy is used thoroughly in the course lectures and in project-related explanations. Similar teaching situations were prepared in the other topics of the course, namely, basic introductions to strength of materials and engineering mathematics.

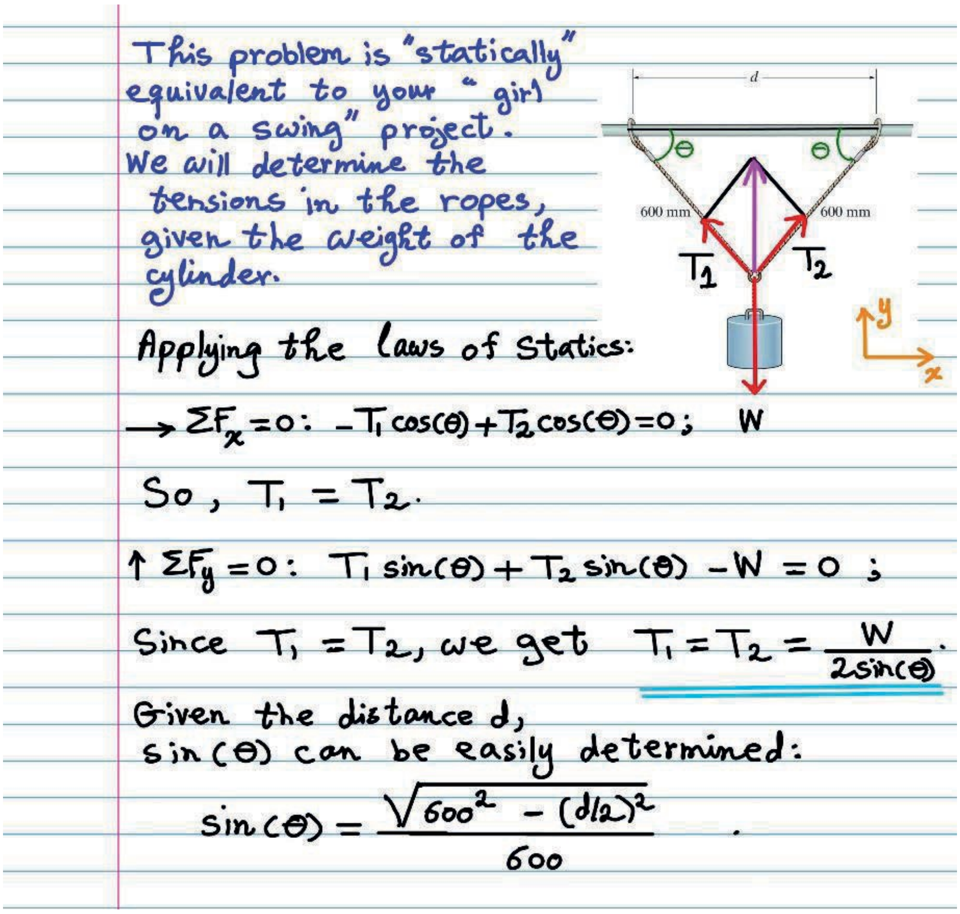

Figure 5: Solution of the sample example

It may seem that this explicit transmission of knowledge, through worked examples, contradicts the essence of PBL, where "knowledge should be constructed" and “not conveyed”. In fact, as Klahr (2009) points out, what some researchers call “direct instruction” is, in fact, very close to what good constructivist pedagogy recommends (p. 297). “Even the most zealous constructivist would acknowledge that there exist combinations of time, place, topic, learner, and context, when it is optimal to simply tell students something, or to show them something, or to give them explicit instruction about something” (p. 291). According to Rosenshine (2009), direct instruction does not mean teaching by direct transmission, but refers broadly to a teacher-guided effective teaching, including revision to find out about the students’ prior knowledge before the teaching of new knowledge, updated lesson plans, opportunities for the students to apply new knowledge and giving students constructive feedback and continuous revision. Direct instruction thus does not necessarily imply that students are devoid of opportunities for active participation. It is therefore a misconception, in “constructivist” theories of education, that teachers should never tell students anything directly but, instead, should always allow them to construct knowledge for themselves. This perspective confuses a theory of pedagogy (teaching) with a theory of knowing (Rosenshine, 2009, p. 11).

4 Examples of Students’ Solutions

In this section, excerpts of the students’ solutions of the course project are shown. Again, the raison d’être of the course project is to integrate different domains of knowledge and communication skills so that the students become able to tackle realistic problems. It is a **work in progress** in the course, since it consists of gradual stages through which the students should go through during the project. Each project group made observations and measurements in the initial stages of the project. The three parts of the project were open-ended regarding the outcomes, and thus, gave the students the freedom to choose an outcome that interests them. For example, some work groups came up with different materials for the cords holding the girl on the swing; others changed the design of the chandelier in the second part of the project so that it had two bars instead of three. According to the project formulation, the students should justify their conclusions and argue for their chosen designs. Given that student reflection is an important aspect in a PBL teaching situation, the students are therefore required to fully evaluate the results they have reached. The figures below show excerpts of students’ solutions of some parts of the project.

The lectures on matrices and linear equations were integrated in a major part of the course, namely, strength of materials. The course project is thus designed to make a connection between linear algebra and the rest of the course, e.g., in the project part “analysis and redesign of a chandelier hanging from a ceiling”, a connection is made between the mathematical statement "two equations in three unknowns" and the fact that "the middle cord is redundant". The culmination of this part was to make students reach the conclusion that a consistent system of three linear equations in three unknowns corresponds to the fact that the three forces in the chords could be determined, and thus to enable them to “see" linear algebra in action. Differential equations are also taught in the context of strength of materials, specifically in lectures on the deflection of beams, to reveal its importance as well as to provide the students with some real-life applications, that are relevant to the program "Sustainable Design".

Figure 6: The forces acting on the girl

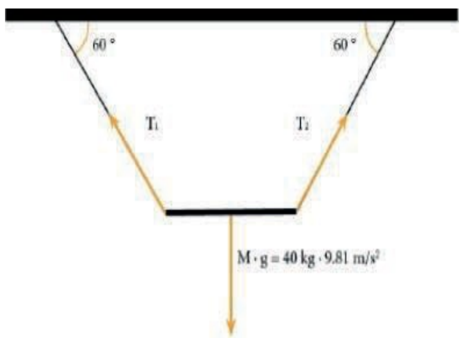

Figure 7: An FBD of the girl

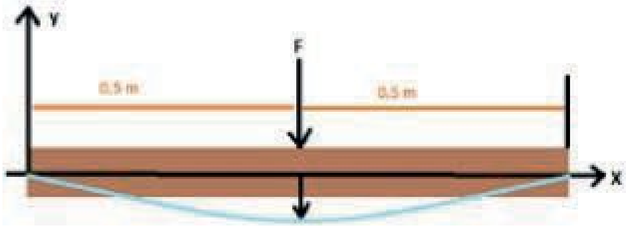

Figure 8: The deflection of the beam

$$E \cdot I \cdot \frac{d^2v}{dx^2} = M(x) \qquad (1)$$

$$E \cdot I \cdot \frac{dv}{dx} = V(x) \qquad (2)$$

Figure 9: Differential equations

Figure 10: Students measuring the deflection of the spring

5 Course Evaluation

The course evaluation is used to provide the instructor and the study board with knowledge of the learning outcomes of the course, in order to continuously improve it and to provide the students with suitable conditions for learning. Implementation of PBL in the course was performed in the Autumn semester 2017 and again in the Autumn semester 2018. A preliminary assessment of this implementation of PBL in the course was made through a survey of the students at the end of the semester. The students' evaluation of the course as well as their comments are made available for the instructor at the course homepage on Moodle. A comparison of student evaluations in the years 2015-2018 is shown in Figure 13.

It was observed that the students' perception of the course was improved considerably, compared with the previous surveys in the years 2015 and 2016. The course then was very teacher-driven and solely consisted of a series of lectures on the course topics, with no project involved or connection to the first semester project. Regarding the relevance of the course, most students agreed that the course project provided a practical illustration of real-life applications of the various fundamental topics covered in the course.

The students felt, however, that they needed more guidance in completing the project. This can be quite challenging to achieve for the instructor, since a balance between the amount of guidance given to the students and the freedom that should be allowed for creativity in an open-ended problem is not easy to find. The introduction of the PBL also changed the interaction and the relation between the instructor and the students quite significantly: The instructor assumed the rules of a project supervisor and a "visiting" group member, in addition to the usual rule as a lecturer. By participating in the group discussions, the instructor gained much insight into how the students tackled the problem, where genuine ideas are shaped and where students fell victims of flaws in their arguments. In fact, this was the most interesting part of the job as a lecturer! The learning environment after the revision was much more focused on the needs of the students, rather than on the strict adherence to the course schedule. This required some flexibility on the instructor's part in responding spontaneously to the project-related problems surfacing during the unstructured discussions and in adjusting the pace of the lecture to the progress made in the course project. In future offerings of the course, some adjustments to the schedule will have to be made.

It is expected that the planning on which specific subjects to cover in the lectures and which ones to move to independent learning through the course project will require some adjustments. Regarding group formation, letting the students determine the composition of the project groups entirely on their own based on friendships and working relationships from the semester project turned out to be, more or less, an adequate choice. Based on this procedure, many groups were formed through mutual agreement of all the members while some other groups essentially consisted of those students who, for some reason or another, were unable to form alliances. While it is rather clear that equal teams with culturally diversity and similarly distributed talent would be desirable, it is much less obvious how such a balanced distribution could be achieved. A group selection by the instructor would not necessarily result in equally strong teams since other qualifications such as previous leadership skills are as important for the group success as are analytic abilities and factual knowledge. Incompatibility due to work schedules and personality conflicts might also turn out as further impediments to the feasibility of the selection by the instructor. Therefore, during the next offering of the course, a random procedure, possibly with some minor adjustments by the instructor, will be adopted. It remains to be seen if such procedure will turn out to befruitful.

Another challenge associated with team-based educational activities is the evaluation of both the individual contributions and achieved skill levels of the group members. Sometimes, student groups tend to cover for under-performing members. In that regard, anonymous questionnaires judging the contributions of all team members, had to be filled out by every student. In cases of obvious extreme discrepancies in the level of contributions, different course grades were assigned for individual students in the group. An analysis of student performance in the oral exams, which were designed to be of similar level of difficulty before and after the implementation of PBL, showed a measurable improvement of the students, grades, especially in the “what if" questions, posed during the exam.

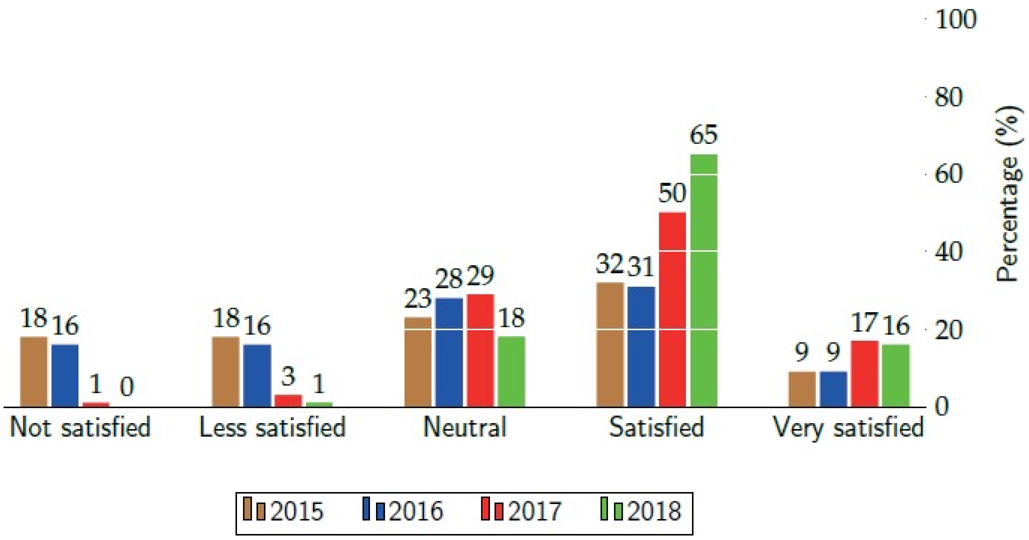

Figure 11: Comparison of student evaluations

6 Discussion and Conclusion

PBL can be successful in design-oriented engineering programs where product design plays a dominant role since "Designing is a many-sided and wide-range activity" (Pahl *et al.*, 2013, p. 27), that is interdisciplinary in nature. This is exactly what we tried to achieve in the course project: To help the students overcoming what appears to them as being disconnected subjects. It seems therefore that PBL may be a partial answer for resolving a critical issue of engineering education, namely the *application context* of the courses given in early stages of an engineering program.

It is generally acknowledged that design is one of the fundamental processes and activities in engineering. The strategy for teaching design, as has been practiced in engineering programs for many years (Dym *et al.*, 2005) shares many similarities with PBL. These similarities have been noted by Williams *et al.* (1994):

- Both methods start with open-ended problems or realistic situations.
- Students' progress in the project is dependent on their own learning.
- Students need to develop motivation and organization skills.
- Both PBL and teaching design have several gradual stages through which to pass in order to acquire new knowledge.
- Observational skills are equally important for both PBL and teaching design, especially in the initial stages of the problem or project.
- Student reflection is an important aspect of both methods.
- Both methods rely on group work.

Hence it would appear that the implementation of PBL is a *logical extension* of the program "Sustainable Design", as both design and PBL are analogous in their approaches. "Design projects play a vital role in providing students with a crucial attribute desired by industry for a newly graduated engineer: The ability to identify and define a problem, develop and evaluate alternative solutions and develop one or more designs to solve the problem. It is generally agreed that this attribute can only be developed by exposing students to the experience of open-ended problem solving which includes linking engineering science knowledge to complex, real-life design problems." (Schjær-Jacobsen *et al.,* 2012, p. 79).

We believe that our experience in implementing PBL in the course strengthens the argument that topics like engineering mechanics and mathematics in design-oriented engineering programs should be taught in a design context, through well-structured teaching situations that allow students to work with real-life problems that they consider beneficial to the society. In fact, solving problems of the society and the environment may be the reason why the students chose the program "Sustainable Design" in the first place.

The preparation time allocated to the course was not enough to fully implement PBL in the course: We had to use some of our free time to choose suitable, authentic problems. The limited duration of the course is also a hindrance: Here, it would be "easier" for the teacher to be the main source of learning in the form of direct transmission of knowledge.

Another issue in implementing PBL in the course, is that our students differ in skills and knowledge, and most of them need a strong guidance to learn. We tried to solve this issue by acting as a visiting member of the student groups, having a double roll:

- We acted like the ancient Greek philosopher Socrates, by asking questions that forced the students to ascertain a fundamental insight in the issue at hand.

- We gave some background knowledge according to the needs of the group visited, to keep the students on the right track.

- We had to make decisions on the spot, considering the different backgrounds of the students while making sure that our teaching project stays on course.

In his plenary speech at the ICME 7 conference in Quebec, Howson (1992) expressed something very interesting, in that he said "I have written elsewhere of the danger that parts of 'mathematics education' will detach themselves from mathematics teaching in much the same way that 'philosophy of mathematics' has drifted well away from 'mathematics' itself. (...). The importance of such studies is not to be denied, but where does that leave the mathematics educator who wants to serve and help teachers, not just to study, count, or assess them? Perhaps it would be a useful check for all of us contributing to this congress to ask of our contribution: How will/could it help teachers, under what conditions and within what timescale?"

We believe that research in education, especially when theoretical, should find its natural validation in practice, not only in the daily managing of classroom activity, but also in the teacher as a decision maker, influenced by important factors such as time constraints, knowledge, experience, beliefs and emotions.

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Linking Action Research and PBL.

A Mexican case of co-creation

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Abstract

This paper suggests innovative tools for creating teaching methods. We are inspired by action research methods about how to bring societal challenges into the curriculum of higher education of tourism. How can we, as responsible educators and researchers, support our students in being not only critical thinkers but being able to position themselves as social agents of change? Our method is to push them (as well as ourselves) towards engaging actively in societal challenges rather than only provide critical analysis from a distance, i.e. within the walls of a university.

The paper seeks to encourage undertaking a more open and sustained exchange of ideas on how teaching critical thinking and creativity can be conducted at present-day universities. We acknowledge universities and our role as facilitators as vital sites of socially activism-oriented engagements. This is aligned with the goal of quality in higher education in Sustainable Development Goal (SDG) no 4, in which qualitative education is encouraged. Our paper explores how 18 Master students at 'Tourism Studies' at Aalborg University, campus Copenhagen (Denmark), co-create new spaces together with local Mexicans and indigenous peoples in Tulum (Mexico), including local authorities, whom all have an interest in turning cenotes/sinkholes, an existing tourism asset, into a sustainable tourism product.

Keywords: Co-creation, Problem Based Learning, action research, Sustainable Development Goals 4 & 17, Tourism master students.

Type of contribution: Best Practice Papers

1 Introduction

Tulum, Mexico is a top tourism destination for tourists from primarily USA, Canada, and Europe. It is located south of Cancun but is very different from the coast around Cancun with its large resort hotels located right at the beach. Tulum is branded as part of the well known 'Mayan Riviera', the hotels at the beach are rather small, and the beach is separated from the town of Tulum by forest and wetlands. The inhabitants in the area were mainly indigenous (Mayan), but due to tourist influx, migrant workers have arrived from many different parts of Mexico (Torres & Momsen, 2005). The majority of these migrants, who work in the service industry and drive taxis, have settled in the area, others come during peak season. The Mayan population is ejidatario[i] and has common ownership of the land by the beach and elsewhere, but many have rented it to (mainly) outsiders, who have built smaller hotels along the beach without formal permissions from either the Mexican state or the ejidatarios, which creates an on-going and increasing conflict between the indigenous population, hotel owners and municipality.

This forms the 'reality' we bring students from the Tourism master program at Aalborg University in to. We aim to position ourselves within action research and we seek to prepare our students to enter and conduct action research as well. In this study trip, Tulum municipality framed their main challenges to the students and they invited the students to collaborate on ideas and generate potential processes to suggest how to change existing practices. Our research question is 'How can we, as responsible educators and researchers, support our students in being not only critical thinkers but being able to position themselves as agents of social change?'

We consider students as agents of social change to be within the field of action research since we assume that students work with stakeholders (for example indigenous people) to change the challenges they are met with and co-create solutions required by stakeholders. Furthermore, change is driven by connecting to SDGs which do give directions towards change in the way they are formulated, but which, on the other hand, also allows for ideas and solutions to emerge from below. We combine our work with SDGs with World Economic Forum's 21st-century skills every student needs to know (especially relevant for SDG goal 4: Quality Education) and life-long learning (see model 1).

2 Context

We went to Tulum together with 18 master students from AAU's Tourism program. We had made a small survey among the students before going, asking what they believed would be the output. We interviewed the students while we were there and we did brief interviews with students after coming back to Denmark. The students form an international group coming from a variety of different countries. At AAU problem-based learning (PBL) is used at all levels and within different disciplines and thus we also base our teaching (and research) on PBL (Andersson & Clausen 2018, Clausen & Andersson 2019).

As students stayed in Tulum for less than two weeks, we had to prepare for their work there, for them to get most out of it. Since we use action research, we did not prepare for specifically *how* to work with stakeholders. Instead, we wanted students to work with intercultural skills and competencies related to classroom learning. Nevertheless, one of us (HBA) has conducted fieldwork in the region for more than fifteen years and access to a range of different stakeholders which is necessary due to the limited timeframe for the study trip. During classes before going to Mexico, students and lecturers had discussed how we would be perceived, when doing work in Tulum, to make students see themselves as part of the context they are investigating (McNiff 2017). Additionally, we wanted them to be aware of how they position themselves and acknowledge that they have different competencies, they can use working with stakeholders (Clausen & Andersson 2020). They were supposed to use their stay in Tulum to change inherent practices within themselves, and they were supposed to work with stakeholders to drive change (from below) in collaboration with for example indigenous people or poor migrants in the town's slum areas. We provided tools for conducting fieldwork and interact respectfully with people in Tulum, to create a foundation on which students could build, but without giving too many directions on how to engage with the field. Before going to Tulum we taught classes of qualitative field work and provided students with cases, which we discussed in class. HBA has unique contacts in Tulum among NGOs, municipality and indigenous peoples' organizations and used these contacts to provide access for students to get to know people locally and to start working with them immediately after arriving to Tulum. It takes time to build trust among people, and students would not have had time to do it during the days they were present in Tulum. Even though students were provided with contacts, they were still supposed to position themselves in creating change in collaboration with partners there. We worked with Sustainable Development Goals 4 (Quality Education[ii]) and 17 (Partnership[iii]) and students used the potential for change embedded in the SDGs as part of doing action research during their stay in Tulum.

Students worked with several different organizations and enterprises in Tulum. They worked with waste and waste management (in slum areas), bicycle tourism, sustainability in beach hotels (traffic, land ownership) and indigenous organizations (rights) among other things. The specific case we present in this paper is a student group that worked with 'cenotes'. Cenotes are sinkholes and there are several open water pool cenotes around Tulum, which are popular among tourists. It is possible to swim, dive and enjoy very special natural phenomena like stalactites formed by the water in the soft limestone.

3 Sustainable Development Goals and 21st Century Skills

The paper explores how Sustainable Development Goals are reworked in light of new contexts and new questions for sustainability using a critical participatory action research perspective. We examine how different cultural and institutional structure underpins the negotiations of the SDG 4 and 17. We associate SDG 17 (partnership) with the results students and stakeholders gain through their co-creation in Tulum by creating innovative solutions to issues identified by local stakeholders and solved in collaboration with students to create an actual change and eventually sustainable development.

Our interest in SDG 4 (Quality Education) is connected to a discussion of 21st-century skills for education, as suggested by the World Economic Forum. The 21st-century skills (see model 1) were proposed by the World Economic Forum as a vision for life-long learning skills, which are different from the present skills taught in schools. SDG 4 and 17, quality education and partnership for sustainable development, are thus important topics, which we can refer to in our work.

Skills for the 21st century is presenting a holistic view regarding teaching and learning. We will address the headlines ‘Competencies’ and ‘Character Qualities’ from the model in this paper. This will be linked to a discussion of the two chosen SDGs. The overwhelming task behind the SDGs where the pledge is: “to leave nobody behind”, requires changes in how to reach the marginalized and poorest in societies and to “think out of the box”, which we believe an action research approach to education might provide in part. We argue that these competencies and qualities support and complement action research since action research is founded on students' and partners' abilities to instigate change.

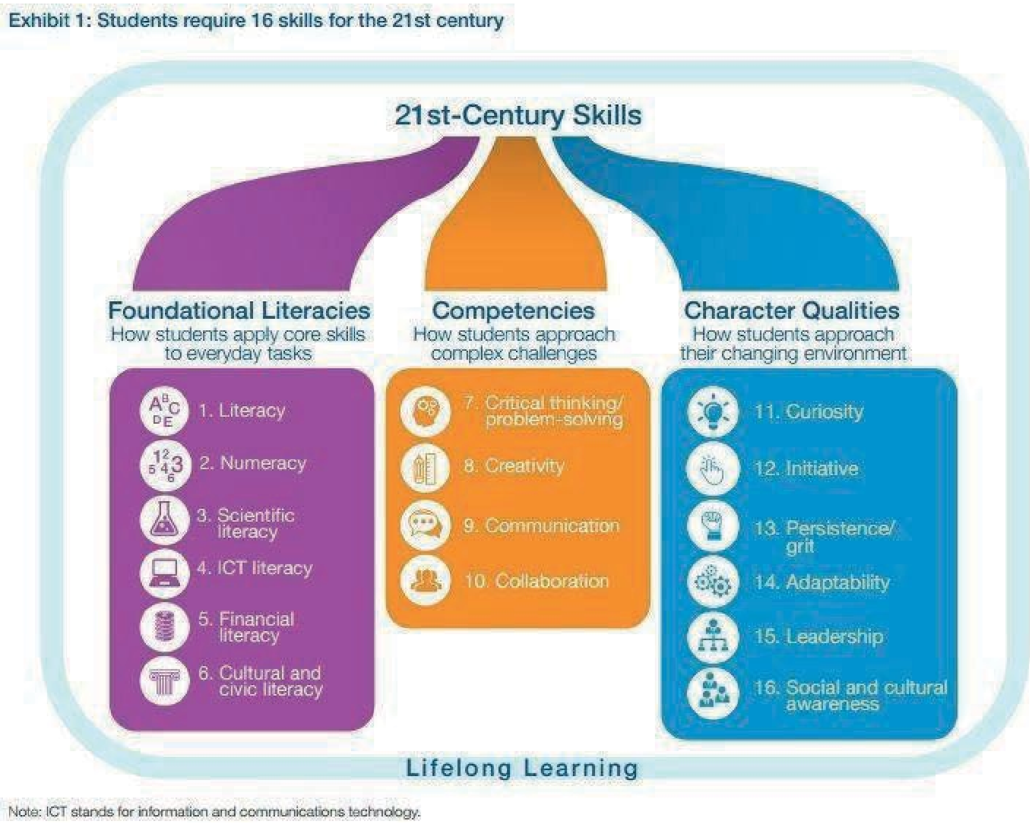

Figure 1: Model 1:21st Century Skills. Source: World Economic Forum *Model 1: 21st Century Skills. Source: World Economic Forum*

4 Methodological Approach: Action Research

Action research is considered to recognize the capacity of people living and working in particular settings to participate actively in all aspects of the research process and the actions taken are oriented towards improving the practices in the settings by the participants themselves (Kemmis et al., 2014). Moreover, it is pivotal that researchers work with and for actors to create change, but the researchers are also considered practitioners with a specific field of knowledge, which they bring into the community or situation. Often, critical participatory action research is strongly represented in the literature of educational action research. It emerges from dissatisfactions with classroom action research, which does typically not take a broad view of the role of the relationship between education and social change; action research also has a strong commitment to participation, as well as to social analyses in the critical social science tradition, which reveal the disempowerment and injustice created in industrialized societies. (Kemmis et al2014).

In this paper, we understand critical participatory action in line with Kemmis et al (2014), who suggest that the way this approach create or recreate new opportunities for what Borda (in Coghlan and Brydan-Miller 2014:806) calls *vivéncia* (human forms of social life), entails analysing how the public sphere is revitalized through practices and promote decolonization of life-worlds. Life-worlds, that are embedded in bureaucratic discourses and institutionalized forms of social relationships, in which the social system is understood (Carr & Kemmis, 1986; Kemmis & McTaggart, 2000; 2005). For critical participatory action research, the criterion of success is not whether participants have followed a specific participatory model faithfully, but whether they have a strong and authentic sense of development and evolution in their *practices*, their *understandings* of their practices, and the *situations* in which theypractice.

Critical participatory action research works at its best when co-participants in the process undertake each of the steps in the spiral of self-reflection collaboratively. Not all theorists of action research place this emphasis on collaboration; they argue that action research is frequently a solitary process of systematic self-reflection. However, we argue that PBL provides an interesting contribution to emphasize the collaborative and co-creation element in action research, and in this respect Schatzki's (2002) understanding, that the object of the research is social becomes relevant. It concerns human co-existence, and the forms that co-existing with others can and should take and the consequences of how they organize and re-organize their collective social practices, which are constituted in the social interaction between people (Schatzki, 2002). Thus, the focus then is on the actual practices, not practices in the abstract. It thus involves learning about the real, material and concrete practices of particular people in particular places. However, as also Kemmis et al (2014) suggest, it is not possible to suspend the abstraction that occurs when we use a name, interpret, etc. but the critical participatory action research specifically emphasizes changing participating stakeholders' particular practices, as in this case study is the practices of the owners[iv] of cenotes. Consequently, we need to recognize that communicative spaces are frequently distorted by power, reputation and status and often those with the power and status might dominate the space. Participants in a public sphere need to develop diplomatic (and sometimes undiplomatic) strategies to redress these kinds of domination and to make space for different voices to be heard. This is especially important when participants are in different positions that give different perspectives on what goes on, and when particular interests are served by the ways, things are currently arranged. In public spheres, participants aim to change the climate of debate, the ways things are thought about, how situations are understood. They aim to generate a sense that alternative ways of doing things are possible and feasible and demonstrate that some of these alternative ways actually work, or that the new ways do indeed resolve problems or overcome dissatisfactions or address issues. In the next section, we will address the case and analyze how critical participatory action research might be an innovative tool to reposition the different actors to reach a common goal despite different agendas and learning intentions.

5 The Mexican tourism setting

Despite being one of the wealthiest states of Mexico, the state of Quintana Roo still has some of Mexico's poorest residents and the fourth-highest rate of malnutrition (OECD, 2017). The rapid development of the mega-resort Cancun boosted tourism dramatically during the 80s and 90s and changed the lives of the Mayan and the mestizo populations in these areas. However, the lack of a trickle-down effect keeps the Maya marginalized and they mainly occupy low paid and unskilled jobs within the tourism sector (Mowforth & Munt, 2015). In some states as Yucatán and Quintana Roo tourism is increasing with such a rapid pace that the local and regional authorities fail to provide services, corporations face increasing demands for philanthropic contributions and long-term service providers and workers were needed to support the resorts. Many indigenous people left the labor-intensive work of cultivating milpa (maize) in the Yucatan interior for tourism jobs (Munro & Zurita, 2011; Interview A, 18th March 2018[v]). Moving to Tulum; during the last ten years, Tulum's population has grown from 7.000 in 2003 to 20.600 in 2015

(INEGI, 2014) due to tourism, and is considered one of Mexico's fastest-growing cities in the Yucatán Peninsula (Plan de Desarrollo Municipal, Tulum). The local economy is now dominated by the tourism industry (Plan de Desarrollo Municipal Tulum). Tulum has elements that cater to a wide range of interests. Its coastal areas are ideal for sun-sea-sand tourism. Aside from these, the area of rich cultural heritage satisfies the needs for cultural tourism while the inland has natural bio reserve and cater for ecotourism. Besides, the range of accommodation is broad including high-quality 5-star hotels at the top end of the market, and holiday villages and small boutique hotels in the middle range to hostels in the less expensive end.

6 The Case -'Cenotes'

As mentioned above one group of students on the trip to Tulum worked with a local entrepreneur who is ejidatario and his ejido has several cenotes. Cenotes are threatened by several factors. In the beginning of the 21st-century tensions between the government and Mayan escalated when the authorities started relocating workers (Mayan populations) to different spaces due to tourism enterprises being interested in constructing properties at the beach, and consequently, making it difficult for residents to access the public beach (Interview A, 18th of March, 2018). With the huge rise in tourism, cenotes received growing interest from transnational entrepreneurs, adventurers, cave divers and researchers and also the Mayan culture is reinvented as part of the tourism product in terms of reframing the symbolic, sacred and romantic storytelling (Munro & Zurita, 2011). Cenotes are ranked top four on TripAdvisors' top 100 most popular things to do in Tulum (TripAdvisor, n.d). Consequently, the local Mayan authorities, the *ejidatarios,* ask for the government to regulate tourism-related to cenotes as these form part of their livelihood and life-worlds.

Much tourism in Tulum and surrounding areas are promoted as sustainable tourism and in this case, tourists themselves are contributing to harm the ecosystem in the area. A group decided to work with this paradox: Sustainable tourism destroys nature. The practices of the tourists in the cenotes were damaging to the very goal the owners had about promoting sustainable tourism. The owners could not regulate due to the government's lack of interference with regulations. By not addressing problems of garbage thrown in the cenotes and the destruction of ecosystems by non certified eco-sunscreen lotion used by tourists in the cenotes, the owner potentially was destroying the livelihood of having a sustainable tourism enterprise. However, there are limits to what the owner can do due to agreements with tour operators and lack regulation from municipality. Some cenotes were so damaged that tourists stopped coming there. The student group visited several cenotes around Tulum and talked to the owners, travel agencies, divers and eco-tourists about their practices in engaging with nature. The unregulated flow of tourists into cenotes puts pressure on natural resources and creates waste and pollution, even though it created a rising income in the short term. Cenote owners need to balance the issues of allowing tourists to create an income and at the same time limiting the number of tourists and change their behavior of adding certified eco-sunscreen lotion and dumping waste. The group made a thorough analysis of different cenotes and the practices of cenote owners in collaboration with them, to elaborate a best practice for a cenote, their owners and visitors. They were doing mind-mapping using visual tools, trying to understand cenote owners' point of view, and contributing with their own knowledge and expertise, thus using action research methods to create a common solution for change. This was done in close collaboration with Cenote owners, the municipality and visitors. Although the municipality from the start did not engage actively, and they only assisted to the workshops organised by the students and participated in the qualitative interviews, but did not engage in the end phase with the exhibition of the students' ideas nor did the comment further on the proposal. Despite the students' presentations with colorful posters and references to research, the municipality did not show any interest in changing their priorities and take the proposals from the students into consideration for the upcoming negotiations about the future tourism strategy, all though sustainability was central. Contrary to the municipality the Cenotes owners showed a keen interest in the proposal about establishing a research network with a chair, who was not owner of a cenote, although Mayan, and with a formal education within sustainability. Despite lacking interest from municipality, the result was a co-creation with people involved and action research, as the group of students presented strategies for change, which would benefit both income and nature-conservation. In their process, they were implementing 21st-century skills of critical thinking, creativity, communication, and collaboration. Furthermore, we argue, they were creating partnerships for sustainable development.

7 Results

Our aim for students was to engage actively in social change. The setting was new for all students, but they managed to create results during their time in Tulum. We see action research as a method, which works well with PBL. Critical participatory action research is much in line with the contents of PBL, and we see a close connection to 21st-century skills in the different strands, which the World Economic Forum establishes. Within 'Foundational Literacies' (How students apply skills to everyday tasks) (model 1) we especially emphasize 'cultural and civic' literacy because we encourage students to listen to the people they work with and try to fit solutions to their needs. Therefore, they should not present themselves as 'experts', but rather as 'partners' in creating change. As stated by Kemmis et al. (2014) researchers can be regarded as practitioners holding valuable knowledge, which they contribute in line with the people with whom they collaborate.

Within the strand of 'Competencies' (how students approach complex challenges), our students, who are used to working within the PBL framework, implement all four competencies mentioned in 21st skills: critical thinking/problem solving; creativity; communication and collaboration, as shown in the cenote case described above. When it comes to' Character Qualities' (how students approach their changing environment) curiosity, adaptability and social awareness are three of the most important matters to characterize students who participate in field trips and the skills they acquire.

When students have obtained skills in critical thinking, adaptability and social and cultural awareness, they can act as change agents, which we have seen in our work with taking students away from university and into the world to work with solutions for change, where they position themselves in creating these solutions. The cenote group worked closely with owners of sustainable tourism enterprises about cenotes, exchanging ideas and seeking to understand the Mayan life-worlds, learning from them and listening to their suggestions. They used their theoretical knowledge from lectures in suggesting networks among cenote owners and students realized that cenote owners needed a person from outside cenote owners circle to coordinate and pressure the municipality to consider regulate tourism in the area as a counter measure against national and international tourist agencies. This way the link to sustainable goals 4 (quality education) and 17 (partnership) was established and became 'visible' for students as a practice which they could work with. The SDGs became perceptible. Thus, as Schatzki (2002) notes, the focus is on actual practices, not practices in the abstract. Action research entails that students realized their own analytical competence by being able to see embedded power structures in the municipality, where ejidos, due to historical reasons are without voice.

8 Conclusion

We perceive students as 'agents of change' when they work as they do in Tulum. They bring competences as university students, which they can use in collaboration with local stakeholders. This way the co-creation of solutions becomes original and applicable in the situation, in which they operate. We do our best to create a space, where students can work in an intercultural setting, respecting people and place and become active partners in a process, which can lead to changes locally, but also in students' perception of what they can accomplish.

Our research question was ‘How can we, as responsible educators and researchers, support our students in being not only critical thinkers but being able to position themselves as social agents of change?’

We have provided some of the suggestions to this question in this paper. We are aware, that context is as important as the make-up of the group of students. As a ‘best-practice’ presentation, this paper can point to ways of creating a process during which students become aware of their potentials, use these potentials, and in process of co-creation, create suggestions for change. We argue that one way to create this process is by linking methods of action research with problem-based learning in creating social activism, as both of these methods point towards studies and work resulting in social change.

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[i] i An ejido is communal land owned by a number of members. Members of ejidos have user rights rather that owner rights to land within the ejido.

[ii] Sustainable Development Goal 4: Ensure inclusive and equitable quality education and promote life-long learning opportunities for all

[iii] Sustainable Development Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development (UN)

[iv] We use the word owners to describe those members who have user rights.

[v] Interviews done during HBA's fieldwork

Varity and Understanding of Problems and Projects

Variation in PBL in different university STEM study programmes: How elastic is PBL?

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Abstract

Aalborg University (AAU) in Denmark practises problem-based learning (PBL) in all study programmes in all faculties. The PBL principles are broadly defined; different study programmes may choose a variety of PBL practices. The purpose of this paper is therefore to analyse how PBL student projects look in a selection of different STEM study programmes and to discuss the elasticity of the PBL principles. One would expect PBL to "look different" when comparing, for instance, projects in the humanities with science, but we want to learn if there is any variation *within* the STEM subjects. We analysed groups of three, four, and seven recent student Bachelor reports (6th semester) from Mathematics, Biology, and Mechanical Engineering, respectively. The subjects are taught and recognised worldwide. We focus on Bachelor reports since they show how students work with their subject by the end of a PBL education. We expect that by choosing the final projects, we avoid "beginner-issues" in PBL as the Bachelor project is the seventh PBL project the students do at AAU so any variation in the projects is not due to students not yet grasping the principles of PBL. The research methodology is documentary analysis of curricula and the reports. The focus is on how the reports describe and analyse their problem and what types of problem the students work with. Our findings show a great variation within problems but mainly the students worked with contrast problems, thus here there is room for even more diversity of projects and elasticity of PBL. Some reports did not apply PBL terminology but instead wrote, for instance, aim. Most projects were discipline projects while two were a kind of multi projects where groups collaborated with another group in different ways. Overall, we saw a great variety of PBL, which testifies to the elastic nature of PBL.

Keywords: STEM education, problem-based, problem variation, project work, Bachelor

Type of contribution: PBL research paper

1. Problem-based learning at Aalborg University

Aalborg University (AAU) in Denmark has, since it was established in 1974, organised all curricula around the principles of problem-based learning (PBL). The PBL practice at AAU has undergone several changes (Dahl et al. 2016; Kolmos et al. 2013), but the PBL *principles* have not changed substantially. The most recent formulation (Askehave et al. 2015) states six PBL principles: (1) the problem as point of departure, (2) projects organised in groups, (3) projects supported by courses, (4) collaboration with a supervisor who acts as a facilitator, external partners and other groups, (5) exemplarity (the project's learning outcomes can be transferred to similar problems relevant to the student's future profession), and (6) student responsibility for learning. The students work in groups with projects where theory is applied to solve or explain either a practical or a theoretical problem. The problem formulation is developed through a problem analysis of an initiating ill-defined problem chosen within a prescribed semester theme. This problem formulation becomes the guide for the project. The project usually accounts for 15 ECTS while the other half of the semester consists of courses that support the project. A PBL introductory course is taught in the first semester to aid the students' work in PBL (Kolmos et al. 2004). Although AAU has shared PBL principles, PBL is exercised with variation across the faculties and the departments. Since AAU does not have a PBL *model*, but PBL *principles*, this allows for flexibility. This is true to the principle of exemplarity as each education programme should be relevant to the students' future profession, but it also raises the question of whether too much "freedom" stretches the PBL to an "anything goes" situation. Therefore, in this paper, we study how PBL is framed in different programmes by analysing the types of problems we see in the student reports and discuss to what extent they reflect the PBL principles.

2. Theoretical approach

2.1 What types of problems do students work with?

Dahl (2018) argues that mathematical problems arise in three different contexts: daily context, professional practical context or in the context of the research society. Problems in all three contexts might be practical or theoretical. In engineering, PBL mostly originates in practical problems concerning issues such as transport, health and sustainability. According to Adolphsen (1997), a practical problem becomes theoretical when it asks 'why' the practical problem has happened, and theoretical problems often arise from the contradictions that one experiences in the confrontation with practical problems. Adolphsen (1997, p. 32-33) further elaborates that a practical problem is a contradiction between what you want and what you can do, and it has the same ontological status as an action. A theoretical problem is an incomprehension, you know what you have, and it has the same ontological status as knowledge. Engineers, however, also work with 'pure' theoretical problems, such as turbulence in fluid flows, in mechanical engineering. Here, theoretical problems may have originated in scientific theories, more specifically on scientific laws, which creates a connection to science. In science, a problem could be a knowledge problem that initiates the learning process, for instance, a description of a natural phenomenon, and the student group should then find or provide an explanation of that phenomenon that satisfies the scientific criteria of the specific subject (De Graaff 2016). In this study, part of the analysis of the projects' problems evaluates to which extent they are theoretical or practical.

However, to get deeper into characterising the problems, we apply the "four shadows of problems" (Holgaard et al. 2017, p. 1072) which are: *anomaly*, *paradox*, *contrast* and *contradiction*. In Qvist's (2004) work, the author describes an anomaly as an exception from the rules/norms that "appears in a way, which differs from what we had expected" (p. 81) and suit projects concerned with unexpected or surprising observations. A paradox is "two sets of facts meeting in contrast" (Holgaard et al. 2017, p. 1072), or an "anomaly that also problematises existing perceptions/theories" (Olsen & Pedersen 2019, p. 35). This could be projects concerned with explaining or solving situations where something happens that ought not to happen. A contrast is "a tension between two conditions that is the desired and the actual condition" (Holgaard et al. 2017, p. 1072), or as stated by Qvist (2004, p. 89): "between a situation of status quo and a possible other situation - a vision". This could be seen in optimisation projects. A contradiction is "a simultaneous statement or relation which mutually excludes each other" (Holgaard et al. 2017, p. 1072). Thus, it is stronger than an anomaly, for instance, condition *a* excludes condition *b*, and vice versa. Holgaard et al. (2017) argue that these abstract problem definitions can be difficult to recognise in practice. We, however, find that the level of detail in those descriptions help characterise the types of problems the students work with, and thus provide a more precise overview of how PBL looks.

2.2 What kind of projects do students work with?

De Graaff and Kolmos (2003) distinguish between three types of projects: task projects, discipline projects and problem projects. In *task projects*, there is a very high level of planning and direction from the supervisor and the problem and the methods are chosen in advance. The students have very little opportunity to make changes to the problem or methods. Such projects are incompatible with PBL principles. However, even if task projects exist at AAU, an analysis of the project reports alone would most likely not reveal this, as reports typically do not contain anything about the process and who made which decisions. The *discipline project* also has a rather high degree of direction from the supervisor as the discipline and methods are chosen in advance, but the groups are allowed to identify and define the problem within guidelines and frames, e.g. a semester theme. These projects are PBL projects since the students have some determination in choosing the problem, which then becomes the point of departure. The *problem project* is when the problem is decided by the students' own initiative and completely directs the choice of both discipline(s) and methods. A problem project can be interdisciplinary. One might discuss if problem projects are "more PBL" than discipline projects. We would agree, but this is an example of the elastic nature of PBL. A criterion in determining whether a project is PBL is to what extent the problem directs the project and if the students have some determination in choosing the problem.

A more recent (Holgaard et al. 2019) way to conceptualise different types of projects at AAU includes the idea of students collaborating not only within a group but also with other groups, see Figure 1:

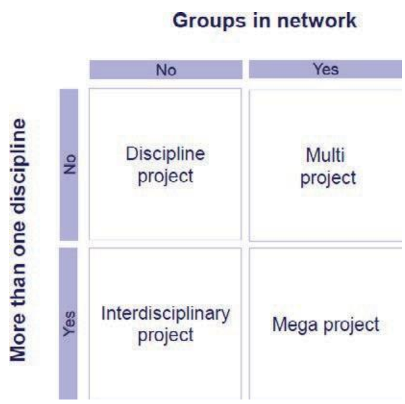

Figure 1: Overview of four types of projects (figure translated from Holgaard et al. 2019)

Discipline projects have the purpose of socialising students into a discipline and deal with well-defined problem fields. In multi projects, students collaborate across teams but within a discipline. Interdisciplinary project groups consist of students from different disciplines. A minor version could be groups including other disciplines as part of their work. They work with an open but rather narrow problem area. Finally, in mega projects, groups work with open and complex problems together with student groups from other disciplines. There is no contradiction between the two ways of conceptualising the types of projects. The types mentioned by Holgaard et al. (2019) do not directly mention problem projects, but it is possible for all four types to be problem projects. The discipline project, however, is the only one of these four types that is a "discipline project" in the sense of De Graaff and Kolmos (2003).

3. The research methodology

We use document analysis as a qualitative research method to analyse the curricula and the students' Bachelor reports. We accessed the curricula either online on the university website or by contacting study secretaries in cases of older curricula. The reports are electronic material since all submitted student reports at AAU can be found on an internal database accessible to all staff. Bowen (2009) noted that "document analysis requires that data be examined and interpreted in order to elicit meaning, gain understanding, and develop empirical knowledge" (p. 27). Unlike other research methods, the main characteristic is a lack of researcher intervention in the documents to be analysed (Bowen 2009). Therefore, it is our own interpretation that needs critical reflection.

We analysed groups of three, four, and seven recent Bachelor reports (6th semester) from Mathematics, Biology, and Mechanical Engineering, respectively. The subjects each represent a central STEM area. We focus on Bachelor reports as they show how students work with their subject by the end of a PBL education. We reviewed the last five years to find a year in which there were at least three Bachelor projects submitted in all three education programmes. This relative high number of projects makes it possible to see some span of projects. We wanted reports from the same year as students would then have had the same kind of PBL introduction the first semester. We chose 2017 and analysed all projectreports.

4. Analysis

All projects are, in principle, group based, but we found examples of a student working alone. The projects are all 15 ECTS. Whenever titles are not in English, we have provided a translation. Table 1 (see after references) presents an overview of the analysis. Here, the letters A, P, Ct, and Cn represent anomaly, paradox, contrast and contradiction, respectively (Holgaard et al. 2017).

4.1 Mathematics

The curriculum (Faculty of Engineering and Science 2010) mentions PBL in the general competence profile for the whole education. For instance, this is done in the skill learning goal about becoming able to apply skills connected with working with problems within mathematics. Another PBL skill learning goal is concerned with being able to communicate scientific problems and solutions to peers, non-specialists or collaborating partners and users. In relation to the Bachelor thesis, the curriculum states that the students should have a large amount of freedom in choosing the subject. The skill learning goals for the Bachelor project, in line with the general competence profile, states that the students are supposed to become able to assess theoretical and practical problems within the subject as well as communicating problems and solution models within the subject to both peers and non-specialists. Thus, PBL and being able to work with both theoretical and practical problems is clearly a central part of the curriculum. These are formulated as part of the skill learning goals. In 2017, three Bachelor projects were submitted.

Project 1. Title: "Analysing Wind Power Time Series Using ARIMA Models" (5 students, 95-page report). In the introduction, the report began by arguing "global warming is an increasing problem in the world". This leads to a discussion of "the application of renewable energy such as wind energy". It also explains that it is impossible to stock wind energy. It then states: "The aim of this report is to examine whether the simple approach of ARIMA models provide sufficient models to forecast wind power, or whether more sophisticated tools must be applied". This project clearly originates in a real problem (global warming) as initiating problem; however, although the "problem" they work with is clear, it is not formulated as an (initiating) problem but as an "aim". This project thus works with a contrast problem as they envision a better solution than the present.

Project 2. Title: "Time series and forecasting wind power" (5 students, 85-page report). This project is quite similar to Project 1. As in Project 1, the introduction discusses the issue of finding alternative energy sources. However, the report deviates from Project 1's report as it has separate sections termed "problem analysis", "thesis statement", and "project delimitation". All terms that are highly influenced by PBL pedagogy. The content of the problem analysis is, however, quite similar to what was written in the introduction to Project 1, both leading to an introduction of the time series analysis of data gathered over time. The section called 'thesis statement', consists of what in PBL is usually termed the problem statement and sounds: "Is it possible to use the theory behind time series to detect patterns in wind power produced and develop a method to forecast productions by using previous observations?" The wording is in fact a problem statement. The delimitation section described, more specifically, which types of time series analysis is used and which are not. This project is clearly termed in PBL language, and as above, presents a contrast problem. Both Project 1 and 2 are practical problems.

Project 3. Title: "Robotics Arms - An Application of Gröbner Bases" (3 students, 61-page report). This project examines the so-called forward and inverse kinematic problem for robotic arms in two and three dimensions. In the introduction, the report begins by discussing that the industry uses robots and that the robotic arm consists of chains of segments and joints that make it possible to move the segments in different directions. The report then explains the forward kinematic problem as "if a certain set of angles are given then where is the hand placed?" The inverse kinematic problem is "what should the angles be if we want the hand to be in a certain position?" The report states that these problems can "be described in different dimensions. For application in the real world, we consider the problem in three dimensions. However, for understanding the problem, we consider two dimensions since this is a simpler case". Thus, although the problem of the report originates in a real world, the actual report is a theoretical report, working with two dimensions as no real robot only works in two dimensions. However, in the report, the group also sometimes looked at three dimensions, but the overall impression is a theoretical report. Although the kinematic problems are termed "problems", the group does not specifically term something a problem statement. It appears that the reference to industry is not the driving force of the project as it is just mentioned one time, line 1 in the introduction of the report, which does not actually justify a practical side as the driving force for the project. The problem is mainly a contrast problem as it deals with explaining how to better control robots.

4.2 Biology

In the competence profile, the curriculum (Faculty of Engineering and Science 2014a) states that the students should gain skills to identify, analyse, interpret, assess and communicate complex problems within biology. Specifically for the Bachelor project, two types of projects are possible depending on whether the students are one-subject students (§3.13.5) or have another subject (*sidefag*) in humanities, social science or natural science (§3.13.6). The learning goals in §3.13.5 do not mention 'problems', but the theme is specified as Aquatic biology. In §3.13.6, however, as part of the description of content, the project should originate in a problem within a defined area within the main parts of the education (there is no specific theme). Furthermore, the competence learning goals state that the student should be able to independently organise and complete a project. Thus, a part of the purpose of the Bachelor projects, and the education as a whole, is to make students work in a problem-based way. In spring 2017, four Bachelor projects were submitted. It was not clear from the projects which of the two types of Bachelor projects they were. They were all in Aquatic biology, thus the project was initiated by practice.

Project 1. Title: "The influences of land use on water quality over different spatial scales – buffer zone versus catchment: A review" (3 students, 27-page report). The report was a literature study with the purpose of determining "whether the land use of the entire catchment or that of the buffer zone is more important in influencing the water quality can help improve land management practices, thus yielding a healthier water quality". Seventeen studies were compared. The report does not explicitly state a problem; however, it is easy to determine that the problem they worked with is how to secure healthier water quality. This appears to be a contrast problem as research does not yet know the answer, but the Bachelor report reveals that different studies have different conclusions.

Project 2. Title: "The effect of macrophytes on nitrate removal in aquatic microcosms" (4 students, 14-page article). The aim of the project is "to evaluate the effect of macrophytes on nitrate removal in aquatic microcosms". Moreover, the article writes: "However, studies accounting for the effect of macrophytes on nitrogen removal and denitrification are lacking". As above, the students do not mention the term "problem"; however, we still see that their work originates as a scientific problem concerning the effect of macrophytes on nitrogen removal, where the research community still does not have sufficient knowledge. As above, the problem is a contrast problem.

Project 3. Title: "Nutrient deposition from colonies of cormorants: A case study from Tofte Lake" (3 students, 48-page report). The group describes the purpose of the project to investigate if a colony of cormorants contribute to the nutrient deposition in a lake: "This is due to the large amount of phosphorous and nitrogen in their droppings deposited to the soil and water in the area of colony". This may have an effect on the water quality, and it is therefore relevant for the implementation of the EU Water Directive. The report states that some of the work was done in collaboration with another group (whose report was not in the system). The two groups collected samples together and afterwards shared the laboratory work. Both groups had access to all results. This is therefore to some degree a multi project. This group also does not specifically state a "problem". Instead, they list three hypotheses they wish to test. The problem is easily discernable as threats to water quality. As above, the problem is a contrast problem.

Project 4. Title: "Eelgrass in the Limfjord [fiord]: growth and sediment" (1 student, 19-page report). This project is a literature review of the problem of eelgrass having "been subject to changes in its natural growing habitat". These changes have resulted in the sediments becoming muddy with low light intensity in large areas of the Limfjord. The project wants to illuminate which factors that affect the spread of eelgrass. This project uses the term "problem" to describe the purpose of the project. As above, the problem is a contrast problem.

4.3 Mechanical engineering

In the competence profile, the curriculum (Faculty of Engineering and Science 2014b) states that the students should gain skills to use modern methods and tools to describe and solve problems on a scientific basis in mechanical engineering and production (manufacturing). Additional competences are obtained through the Bachelor project and includes that the students must be able to indicate how a relatively complicated product is specified, constructed, managed and produced, and to document this professionally. During the project, the students have to gain the skill of becoming able to design a mechanical system based on a *well-defined problem*, which must meet a number of requirements in terms of price, low weight, dynamic performance, control and regulation, material and process selection. As an overall competence, they have to involve at least two significant engineering disciplines and explain how these disciplines respectively affect and depend on each other. In spring 2017, seven Bachelor projects were submitted.

Project 1. Title: "Baseplate with adjustable stiffness" (4 students, 76-page report). The problem is introduced by Grundfos, a pump producing company. It discusses when customers install the industrial pumps and the foundation does not meet the recommendations from Grundfos. An unfavourable foundation can result in noise "from the vibrations from the pump and motor going through the baseplate and further transfer energy to the foundation". The initial problem formulation was: How can resonance in the working frequencies be avoided by constructing a baseplate with adjustable stiffness in relation to the foundation stiffness? After a problem analysis, the group ended up with the following problem formulation: How can a passive vibration isolator be designed to avoid excessive vibration levels on the foundation of a vertical pump system and how can the vibration isolators be altered so the stiffness of the baseplate can be adjusted? This is a contrast problem because the students want to reach a better functioning product.

Project 2. Title: "Design of a movable theater lamp" (1 student, 55-page report). A system of automated movement of a theatrical lamp is investigated in the project. The thesis is based on a case from a local music venue, where there is a wish to add flexibility to older, non-automated lamps. The purpose is to increase the management possibilities during the concerts by having movable lamps within a limited budget. The problem formulation is: "How can a PAR-64 lamp be modified so that the light beam can be moved and thus the lamp becomes an alternative to purchasing new lamps." The results of the problem analyses were to establish technical criteria for the dimensioning of construction and motors so that it can be applied to a local venue. As above, the problem is a contrast problem.

Project 3. Title: “Design and Modelling of Planar 3-DoF Robot” (4 students, 175-page report). The aim of this project is to improve a three degrees-of-freedom system, a task the group was given by their supervisor. The focus of this report was analysing a 3-DoF system by using a CAD model and finding possible improvements for the current system. The problem formulation is: How can a planar 3-DoF robot be designed and modelled so the workspace area and the driving forces of the system are improved? This improvement of the product represents a contrast problem.

Project 4. Title: “Design of Active Rear Wing for Formula Student Race Car” (3 students, 149-page report). There is no stated problem but *a wish to improve* an existing formula student race car from AAU. They sought to improve the car by designing a rear wing. The wish to design a versatile product was stated based on the following two active functions defined: (1) reduce drag to decrease air resistance and (2) improve braking to increase braking performance. As a reason for employing a rear wing, or aerodynamic elements in general, the need to increase the force acting on the wheels by pushing the car down is mentioned. The rear wing, which is to be designed, must comply with relevant rules and regulations. The project objective, the concepts of an active drag reduction system and an active braking system were presented as well as ways to actively implement the two systems. Again, this is a contrast problem.

Project 5. Title: “Development of Laser scanning system & Study of Laser Bonding” (4 students, 93- page report). The project is part of the laser processing research in the Department of Mechanical and Manufacturing Engineering at AAU, dealing with the development of a system of high-speed laser processes. This project has been worked on before, and two previous groups in previous years have designed a laser booth and procured the necessary equipment. This group wants to finish the work. The project deals with various topics related to this technical development project, for which the desired results are high speeds and thus a reduction of process times. It is a contrast problem. However, the project is different from the others because it builds on two other student projects. We could argue that it is part of a multi project.

Project 6. Title: “Energy consumption of 2 DOF robotic arm - Set up analysis tool” (4 students, 136- page report). In the report, the students mention the relevance of streamlining industrial robots that are entering Denmark. The aim of the project is to develop an analysis tool through which the influence of specified parameters on the energy required to power a two DOF planar robot arm can be studied. The investigated parameters with an influence on the required energy of the motors, are defined as follows: link length, outer radius of the two links, factor of safety (FOS) and the trajectory. The investigation has its starting point in a case, which states that the robot arm must be able to transport an object with a mass of 5 kg. The said object must be moved between two predefined coordinates; from (0,4 m : 0,2 m) to (0,8 m: 0,7 m) in a matter of three seconds. The following problem statement is: How can an analysis tool be developed in order to determine the lowest energy consumption of the motors, searching among the combinations generated when combining ranges of investigated design parameters? It is a contrast problem.

Project 7. “Corrosion of helix tubes” (4 students, 92-page report). The starting point is a problem posed by the company Alfa Laval, which deals with corrosion of helix pipes in OC-TCi boilers. The OC-TCi boilers contain both straight tubes and helix tubes where the helix pipes corrode significantly more strongly than the proper pipes despite being located in the same boiler water. This leads to the project's initiating problem: what causes the helix embossed pipes to corrode before the proper (right) pipes? After the problem analyses, the group stated the problem that the helix pipes corrode more than the right pipes, despite measures aimed at reducing corrosion in general. In analysing the initiating problem, the types of corrosion, stress corrosion and strain corrosion (SICC), pitting and crack growth were found to be relevant to the OC-TCi. This leads to the main question of the project: What corrosion mechanism causes the helix embossed pipes to corrode before the proper pipes, and how can a possible redesign of the pipes meet this corrosion mechanism? This project differs from the others. We face a paradox. Two different pipes corrode at various speeds, despite being located in the same boiler water.

5. Discussion and conclusion

We sometimes saw that the projects do not use the term problem even though a problem was easy to identify. We did not have the opportunity to interview the students about this, which might have provided interesting background. However, for a PBL university, it seems odd to not apply PBL terminology such as "problem". Why did students not use this terminology? One answer might be that the students are so used to thinking in problems, that they no longer see the need to use the specific terminology. Another explanation could be the question of why the specific term "problem" is so important if it is otherwise clear what the project is about? The students might not be clear about the terms research question, thesis statement and problem formulation and perceive them as synonymous.

We noticed a wide range in the length of the Bachelor projects (14–175 pages) as well as in the number of students working together (1–6). It is worth noting that for Mechanical Engineering, there is a requirement of a maximum of four students in the group (Faculty of Engineering and Science 2014b). One Biology report was an article. It is a sign of the elastic nature of PBL to see Bachelor projects of such variety. Furthermore, even though some reports were clearly shorter than others, this does not mean less work was involved as the collection and analysis of samples in a laboratory is a time-consuming part of a project. It appears a bit odd that the average number of pages per student is very varied: 3–55 pages. However, discipline traditions of how long a "good project looks" may also have an impact, which we were not able to study in this paper. The curricula all described PBL as a basis for the Bachelor projects. We, however, did see some differences in some of the details. For instance, in biology, PBL was included mainly as part of the competence goals, whereas for mathematics and mechanical engineering, it was part of the skillgoals.

We also saw great variety in origins of the problems. Some were clearly external, for instance coming from companies, while others were not. One might argue to what extent a project originating from a company or a supervisor's research project is true PBL since the students may not have much say in determining the problem. On the other hand, such problems are clearly exemplary. Here you can argue that a problem from a company is very often an initiating problem. Afterwards, the students must decide what to include in the problem analyses to state the problem they wish to solve. In fact, the students in this situation define the problems themselves, which supports the finding from Nørgaard et al. (2017). Hence, they have taken ownership of the problem. In any case, this is an example of the necessary elastic element of PBL at AAU — and also why we need the fifth principle of exemplarity.

As illustrated in Table 1, most projects were discipline projects, but on two occasions, we found projects that had a resemblance to multi projects. In the project where the group continued the work of previous groups, the initiating problem did not come from the students themselves, but they bought in/took ownership of an existing problem and continued the work. This might also be an example of the exemplary and elastic nature of PBL. We saw that most projects were initiated by practical challenges. Sometimes (MA3) a practical initiating problem appears to have the started project, but when reading the whole report, it appeared to only have had a very minor role.

Finally, concerning the four problem types, anomaly, paradox, contrast and contradiction, as seen in Table 1, most projects were about contrast problems, but these were quite different. Further study into the nature of problems would need to see if this category could be divided into sub-categories. We did wonder why we did not see many other problems. Here, it appears that PBL at AAU might be less elastic than it should be. More variety in problem types would still be PBL but might teach the students even more PBL skills and competencies.

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Education	Problem Type								Project Type			
	Purely theoretic				Initiated by practice				Disciplinary	Inter-disciplinary	Multi	Mega
	A	P	Ct	Cn	A	P	Ct	Cn				
MA 1							X		X			
MA 2							X		X			
MA 3			X						X			
BIO 1							X		X			
BIO 2							X		X			
BIO 3							X		X			
BIO 4							X		(X)		(X)	
Mech 1							X		X			
Mech 2							X		X			
Mech 3							X		X			
Mech 4							X		X			
Mech 5							X				X	
Mech 6							X		X			
Mech 7						X			X			

Table 1: Overview of analysis

Information management impacts when students configure the project-work

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Abstract

Usually, a beginning activity in PBL is seeking available information relevant to the decision-making to configure the project-work. How students deal with that information has effects in both the learning outcomes and the project product. In this context, Aalborg University has structured the project-work to students can learn through while working in the project. Students begin their undergraduate program learning how to work projects by an initial short project P0, followed by a more extended subject project P1, to be accomplished in about three-quarters of a semester. This study explores how students address the project information when setting the project-work. 17 participants from two engineering programs answered open-ended interviews. Then, the study used a verbatim transcription by Thematic Analysis for code and correlations. The results indicate impacts in several features such as identification, search, quality and share of information, among others as roles and task assignment.

Keywords: Project-work, PBL implementation, group performance, learning, culture

Type of contribution: PBL research

1 Introduction

Among skills, the curricular Learning Outcomes must include search, selection and categorization of relevant information for a task (ABET, 2019; Lattuca et al., 2006; Shuman, 2005). The information management capacity helps the collaborative project-work since it facilitates the process of information sharing between team members and, consequently, performing a working plan. After identifying a problem area or theme, the first task of the team members is to seek for the pertinent and coherent information that will lead them with rigour to the problem formulation (incl. specifications for a given product). This information includes identification of topics, issues about the problem, existing solutions available in the market, identification of knowledge gaps, identification of solution methods, and identification of stakeholders

Unfortunately, the implementation of information management skills in the curriculum is one of the critical aspects of skills development which has not had satisfactory results (Chen et al., 2013; Dobbs et al., 2015; Enders et al., 2019; Moore et al., 2018). There could be many factors influencing results such as the technological revolution, and social networks, which have made the flow and availability of information greater. Likewise, there could be a gap between what students of the Generation Z face compared in what Millennials continue doing, or which approaches those of early generations are accustomed to each one seeking and managing information in different ways (Abram, 2007a, 2007b; Grenčíková & Vojtovič, 2017; Taylor, 2012).

In project-work, students must solve an engineering problem in a specific area of knowledge, but in a collaborative team. In PBL, the problem usually comes from a real situation. These problems often are complicated for the students due to lacking knowledge and experience in the subject area. For first semester students, the lack of soft skills is an additional factor in this complexity, making problems seem harder to solve for them. On the learning cycle, when a problem first occurs, it is expected that in the early stages of the project, students will focus on the issue and the process reflecting about information and ways to solve problems. In PBL, the problem formulation view as a central stage, the formulation includes the purpose, the context and both the project methodology and the possible methods of solving the problem.

The main purpose of project-work is giving a media for students' learning. It begins when students deal with information to organize a project. Thus, understanding how first semester students address information can help improve project-work methods, including guidelines and recommendations for facilitation, and implementing modern active learning strategies to the project-work principles.

2 Information behaviour

The problem formulation and its subsequent solution require accessing and seeking for information. However, the way information is searched for and used depends on both the expertise and the role of who does it. Researchers and university students look for information in databases with the resources made available in those universities, in magazines and through Internet search engines (Allard et al., 2009). In turn, graduate researchers and staff in organizations have traditionally searched for information in internal documents such as reports or from other colleagues, but currently, they are doing it by using search engines (Chaudhry & Al-Mahmud, 2015; Leckie et al., 1996). How they search for or can access the information will determine the search behaviour, the value and the use of transmitted data.

While in the late twentieth-century, engineering information was sought from internal organisational sources, where oral communication on technical knowledge predominated predominated (Fullerton & Leckie, 1999; Leckie et al., 1996), in the first decade of 2000, the search began to be carried out in other types of non-human information sources and using the assistance of others, as highlighted by Wellings and Casselden (2019). However, recent reports show that search behaviour has changed and has focused on information systems (Johri et al., 2014). Nevertheless, Generation Z or post-millennials, that is those born since 1997, are using social networks to obtain the information they need and resorting to informal sources of information (Mercer et al., 2019; Zhitomirsky-Geffet & Blau, 2017). This generation began university studies after 2015. Those information sources often are viewed as non-valid for technical and scientific projects in PBL.

In academia, students share information informally without the necessary knowledge for recognizing and finding reliable sources of information (Mercer et al., 2019). Furthermore, there is excessive confidence in the students' thinking that their abilities to find information are superior to those of staff like teachers, researchers or engineers, producing in them low levels of frustration (Phillips et al., 2019). Consequently, mutual learning turns difficult among the university students since the recommendations of the facilitators may not be considered.

However, when students are enrolling into the university, the behavior with the information is different between them. Students must deal with a higher number of sources of data compared to requirements in a high school library. Hence, they do not have sufficient skills to search for valid or reliable information leading to issues with the problem solving, and at the same time leading to issues in collecting an irrelevant amount of data from online searches (EBSCO, 2019).

This study adds knowledge about the work-process of PBL for the early stages of problem-formulation among students with a scarce background in project-work. The study seeks to answer the following research question: What information behavior do the first-year engineering students apply for the project-work? Additionally, the study addresses a sub-question: How are students addressing the information seeking?

3 Methodology

The study uses a case to answer the research questions. The participants were students from the first semester of the Mechanical Engineering and Energy Engineering programs at Aalborg University in the fall semester of 2017. The researcher interviewed 17/83 students who voluntarily agreed to participate. Each one of the participants was interviewed individually close to the project deadline. Students were from four project-work teams. The open-ended interviews lasted around 30 minutes each. They were videotaped, answered in English and transcribed verbatim. All students participated in the 30 ECTS semester activities, including the 10 ECTS collaborative PBL-project and the 5 ECTS course “Introduction to PBL”, and all had previously completed a short-term pilot-project of 5 ECTS during the initial weeks. During the pilot-project, teachers and facilitators introduce students to project-work and problem formulation, according to the Aalborg PBL model (Aalborg University, 2015). In the following first semester project, the students apply the acquired skills to develop a disciplinary project chosen from a pool of approximately 10 projects aligned with the first semester curriculum. The open-ended interviews were conducted near the project-report submission deadline, focusing on several topics. The researcher will analyse the data thematically seeking recurring patterns and associations between those patterns (Braun et al., 2008; Terry et al., 2017).

The Thematic Analysis (TA) searches for relevant topics among the participants' verbatim responses. The study will use NVivo version 12 (QSR, 2015) to facilitate pattern searching among the responses. In addition, NVivo will help to analyse the answers from the coding and then grouping for themes in recurrent readings. It concludes by looking for association of patterns between the participants' responses.

4 Findings

Table 1 shows the themes found for the 17 participants according to their verbatim transcription. The analysis of information behaviour produces five groups with their sub-themes: Information Management (IM), skills, supervision, conflicts, and sharing.

The IM theme refers to the way students managed information in the project-work and the time they spent on it, as well. The IM has 11 relevant sub-topics described in Table 1. The sub-topics with the highest number of participants and recurrences indicate a consensus among students on initial information, information sources, classification, quality, and spending time in organizing data. In addition, the analysis found sub-themes regarding tasks to address information with roles and assignments. In this category, two subthemes describing how the students write relevant data for the report in parallel, i.e. when some were doing it simultaneously, or in serial when everyone writes the same step by step. Finally, just with a single participant, how the students store data, i.e. in the cloud.

The students’ skills theme, mainly characterized by the lack of background regarding information for the problem formulation and its identification, as table 1 shows. In addition, this theme includes lacking experience in the project-subject, satisfaction for project-work, and abilities to search or find relevant information

Supervision grouped themes relates to the students' perception over the supervisors' role but also the understanding of the supervisors' experience with the relevant information to formulate and develop the project. Also, the TA found sub-themes such as lack of interaction with the supervisor for no get a negative personal reputation. Besides, two students declared some negative attitude in supervisors to provide data.

Information Conflicts (IC) refers to the spending energy of the individual to carry out the project tasks. The IC includes changes in motivation, internal struggles to address information, and the perceived consequences of the individual on the job on collecting data. Besides, five sub-themes emerged as consequences of conflicts such as a lot of information, frustration, randomness, few data collected and starting the project-work too late.

Sharing information is student perception about how any information with value was communicated between team members. These were divided into two sub-themes: effectiveness and meetings.

Table 1: Themes and recurrences regarding information

Theme	Participants	Recurrences
Information Management	17	409
Initial information	17	159
Information sources	14	68
Information classification	10	70
Information quality	10	27
Spending time	9	41
Having roles	6	20
Task assignation	3	5
Information purpose	3	4
Information is sequential for the report	1	7
Information is parallel for convenience	1	4
Cloud to manage	1	4
Skills	17	397
Information background	17	211
Information identification	13	117
Search satisfaction	8	30
Skills in search information	7	22
Subject knowledge background	6	17
Supervisor and information	17	103
Comes from supervisor	15	32
Supervisor knows information	9	44
Avoid because our background	2	9
Behaviourism	2	2
Expected from supervisor	1	16
Information conflicts	16	116
Lot of information	15	86
Frustration	6	14
Information is random	3	6
Minimal information	3	6
Start late	3	4
Share information	6	18
Effectively	6	16
In meeting	2	2

Figure 1 shows themes with the highest score from student interviews in TA. Dealing with initial information, information sources and information identification were the more recurrent claims followed by themes about information management, lot of data available, and information origin. The bigger the area the more relevant is for the students, helping to for cluster analysis in discussion section.

After coding students' interview answers with TA, the researcher selected themes with the highest recurrence and participation among the students to find a correlation between them. The mechanism to associate themes is the word frequency from the declared argument in the verbatim transcription. Correlation and word frequency with NVivo produced the grouping cluster shown in Figure 2. The cluster will be the starting point for the discussion in the next section.

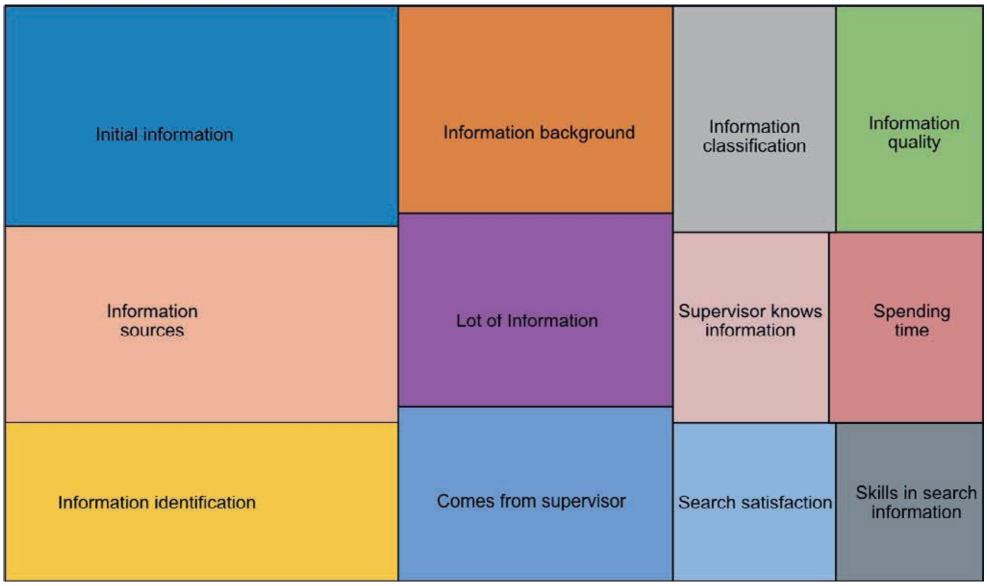

Figure 1: Relevant themes select by recurrence. Adapted from Nvivo 12

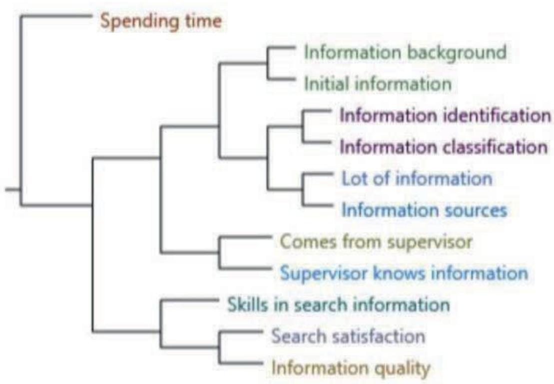

Figure 2: Themes clustered by word similarities. Taken from Nvivo 12

5 Discussion

The findings in Figure 2 are consistent with the purpose of the PBL learning principles. In PBL, there is a premise about the students' responsibility in their learning as is pointed out by Kolmos and de Graaff (Kolmos et al., 2009; Kolmos & de Graaff, 2015). The complexity of the information and the initial lack of knowledge in the information push students to identify, collect and classify data to formulate the project problem that is a core in the Aalborg model (Holgaard et al., 2017). It was the more recurrent aspect grouping in 6 from 28 other themes.

The Figure 2 on the upper right side indicates a relationship between the students' experience and how they deal with the initial information. There is coherence with the project-work problem formulation. It could be explained moving ahead into the branches in the figure. These are marked by four main themes: (1) identification of information, (2) sources, (3) the amount and, (4) classification of data. As it emerged from the students' answers, at the late stage of the project-work and before receiving feedback on its results, it is evident that the students are aware of how important the information for the project is.

Identifying information is a skill that students must acquire during the project-work. That skill is not only an accreditation requirement (ABET, 2015; EUR-ACE, 2015), but it is a skill expected to lead project-work (de Graaff et al., 2016; Kofoed et al., 2003).

One student said:

> *"… it was a bit hard to decide because it said the technology in cell, relate to navigation, we found it's it's very new and they're still being launched a lot of newer methods and technologies, so those... had to find out what what do we were going to use and what was what is the best technology when there's always coming out new technologies… Student" S4*

Seeking information is not restricted to databases, as students also tried to identify information from various external sources, causing them to use alternative ways to do tasks. Two other students said:

> *"…we had, we had interview with the Danish Red Cross, about how they built this, the kind of emergency, disaster, the…" S1*

> *"sources because. what useful. what's not. what is reliable. so, we…" S2*

> *"well, cutting it down to the information you wanted, was was very difficult part, finding individual information was easy enough, just google something else, or use university hear is, that's a base search site for every put in the report, to resolved it, or uses it for a copy and listening to, very convenient, so the information was easy to get, but the hard part was clearly to care down for what is wanted to use" S3*

The above references are from questions related to the early stages of the project. At the end of the semester process, the students changed their minds about some aspects.

> *"…information, something like, the most of the information we used for our project…" S4*

> *"… yes, yes, starting and finding this information immediately was very helpful, it wasn't a wasted all, because we all read something different meaning that we have a different understanding this diversity…" S5*

Other engineering studies have also found that students spend more time in the problem formulation stages (Atman et al., 2013).

However, starting the project, there was uncertainty about the information and the lack of knowledge for collecting it. When students have to deal with uncertainty, learning happens (Rogers, 1965). However, its excess can cause unmotivated project-work as evidenced by students' answers related to early project stages; which is aligned with other studies (EBSCO, 2019). The branches of Figure 2 form two dyads of themes that are directly related, which in turn are paired between them. These are the identification and classification with the amount of information and the sources of information. Seemingly, there was a change from the beginning to the end of the project without any stress at the end for the outcome submission.

"still using it now, because now with all the things we, all the knowledge will gather…"
S6

"…informative, we found a lot of information that I didn't know about in the beginning…" S7

Students recognized flaws in the ability to collect information, and then classify it. Structuring information is another skill that students must acquire. Students invested time structuring data as a task of the project-work. Several learning theories argue learning by doing (e.g. Kolb, 1984), meaning that if the project outcome was successful, this task supported student learning. In addition, it increases the self-efficacy as is stated in other studies (Phillips & Zwicky, 2018). One of the students' responses in this regardwas:

"…and to use everything, we spent a lot of time on structuring it properly and organising more I need it would I guess, say we spent bit too much time structure I'd say in the good part." S8

Below the information branches, there are two more related to the supervisor. The students recognize the supervisor's relevance for the project, being confident about his expertise. Thus, students understand the supervisor as one of the sources of information. That view could happen with two dynamics discussed in detail later. One of the dynamics is when the supervisor is reflective, encouraging students' reflection, causing questions that the supervisor answers. The other is a passive dynamic as the supervisor indicates where to look for the information, showing a path that students must take. Whatever the dynamics, together with the previous paragraph, it contradicts previous studies indicating that current generations believe they know much more and that they also approach information towards informality and ease (Anderson et al., 2001; Masters et al., 2008; Zhitomirsky-Geffet & Blau, 2017).

"…informative, we found a lot of information that I didn't know about in the beginning, and we have also have…" S9

The students waited for the supervisor to give them particular information they needed for the project. However, in line with the skills that students must acquire, supervisors were generally cooperative. One answer indicates a misperception about the role of supervisors, but other indicates cooperation.

"well we try to get more information from our what's called, supervisor but she" S10

" …you want to get more knowledge than you are free to ask them, and then theywill willingly give information to you, so I think that the level of figure out was very good…"
S11

"yeah sometimes we didn't know how to do things and then we just drive it out. And then, then we got something that probably showed us where we had our understanding and that was not correct with that ask our supervisor and he will correct us and say oh, this is something that you need to work on that this is how itworks. Yeah, we can always get help if something we don't understand" S12

At the same time, previous answers indicate that supervisors meet students solely for project issues. In addition, students found support from them to improve skills in information management.

"…therefore the teacher and I try to use this information to me understand how is…yeah this is yeah with the help of the supervisor it was easier…" S13

The last three arms in the lower-left area of the figure indicate the abilities to find information. The students' perception appears to be mediated by the satisfaction and quality of the information found. Students use various sources of information such as scientific articles, databases and external sources, which is consistent with the other studies (Wertz et al., 2013).

"…we set that from the beginning we made the very clear that we're gonna be good sources like books or articles, science articles from the internet and then you…"S14

"…find good resources. the MAN diesel and Travels. the company which makes these engines so that we could research yeah it was it was pretty it was pretty good of sources". S 15

Oppositely, other studies stated that first semester students handle mainly electronic information (Tenopir et al., 2010) for them and mainly from the internet or nearby experts to them.

As in the Aalborg model, students in any project work proposal must organize the information for their learning. Similar problems with the handling of information have been found in the learning models of various disciplines and models (e.g. Johri et al., 2014; Jones, 2017). As the information behaviour showed lack of skills in first-semester students, it could be learned as demonstrated by studies that indicate that advanced semester students manage information better than those of the first semester (Douglas et al., 2014). Thus, it could be learned early to get better learning from the beginning to the end of a curricular program.

6 Conclusion and future work

The study identifies relevant aspects of two introductory engineering programs within a curricular model of PBL. The information behavior of the PBL students supports that PBL is a useful practice to develop and support information skill in the students. Then, PBL has some differences with other general studies regarding information behavior in introductory students.

The study showed several ingredients of information management within PBL. The first one refers to the identification of the information, classification and relevance for the project-work. The second aspect is the role of the supervisor to promote reflection during the project-work and encourage skills in handling data. The third key aspect was the skilled background of the students to find information from rigorous sources, including external sources. Conflicts with information were marked by uncertainty when addressing the problem formulation. Both a lot of information and a lot of sources explain those information conflicts while developing learning in the project-work. At the same time, it became clear that a good portion of project-work, in the early stages, is consumed by getting information.

Since, the information behaviour is cultural, student experience the same issues for many other disciplines and models. Implementing strategies for facilitated student learning plays a role in favour of education. Future work includes answering questions like: What was the relationship between information behaviour and learning outcomes? Perhaps by reconfiguring the project-work intented outcomes in a model, both the product and the process could change student behaviours towards information management.

The study refers to the behaviour of the students with the information, therefore it is situational and therefore culture plays an important role. It could be interesting to find the relationship between the role played by individualistic versus collectivist cultures, or the relationship between idiocentric and allocentric behavioural particularities by some cultures. These characteristics of individuals in culture could have an effect on the ability to search for and share information as well as to manage it.

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A Systematic Review on Frameworks of Project-Based Learning

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Abstract

The statistics from All India Council for Technical Education, New Delhi (AICTE) says that the percentage of students getting recruited every year in the past six years (2013-2018) is in the range of 40.6 to 46.6%. The statistics imply that the current engineering education ecosystem is unable to prepare learners to be competent workplace engineers. The focus of employers today is on problem-solving and critical thinking skills. Learning focused on remembering and understanding using conventional lecture-based pedagogy for student engagement is attributed to be one of the reasons for low employability skills. It is evident from the literature that PBL as a practice can build competencies that enhance employability skills. The success stories of PBL across the globe for different educational settings describe the effectiveness of PBL. Successful deployment of PBL pedagogy requires educators to make well-informed decisions on several elements that together contribute to the enriching of the learning ecosystem. However, in India, authors observe that the research towards adopting PBL practices in engineering education is characterized by variations in understanding of PBL coupled with an inadequate number of practitioners and researchers matching the requirements of the country.

A study of literature on PBL reveals that there are several variations of PBL practised by educators. These variations offer a challenge to the educators in terms of choosing the one that is ideally suited for their context. A good understanding of PBL variations and learning context will help educators to select the right one, to begin with, PBL experimentation. In this paper, authors have reviewed six popular PBL frameworks that are in practice. Further, learning context ischaracterized in terms of nature of problems, nature of teams, nature of student engagement, need for scaffolding, need for formative and summative assessments. Finally, a conceptual framework that helps educators to choose the appropriate PBL model suiting the learning context is proposed.

Keywords Project-Based Learning (PBL) framework, PBL model, Engineering Education research

Type of contribution: PBL research or PBL review/ conceptual paper

1 Introduction

All India Council for Technical Education, New Delhi (AICTE) - a statutory body of the Govt. of India shows the statistics, which reflects that in the past six years the passing percentage of engineering students lies in the range of 39.86 % to 43.11% (AICTE statistics 2020) while the percentage of students getting recruited every year is in the range of 40.6% to 46.6%. Several reasons can be attributed to this scenario and the major one being inadequate technical and professional competencies among the learners at the end of the program. These statistics are alarming and imply that the current practices and pedagogies used in engineering education are insufficient and inefficient to prepare competent workplace engineers.

Authors suggest a list of problems in the field of engineering education and classify them into four categories namely educational, societal, professional and political. These are represented in the fishbone diagram, as shown in Figure 1. The problems include a large number of affiliated colleges having no or very less academic freedom to reframe the content or syllabus, setting the assessment occasions to challenge the students' learnings, usage of active learning methods that suit millennial, thus leading to problems related to low motivation and poor performance among student fraternity, finally making students less competent for the workplace.

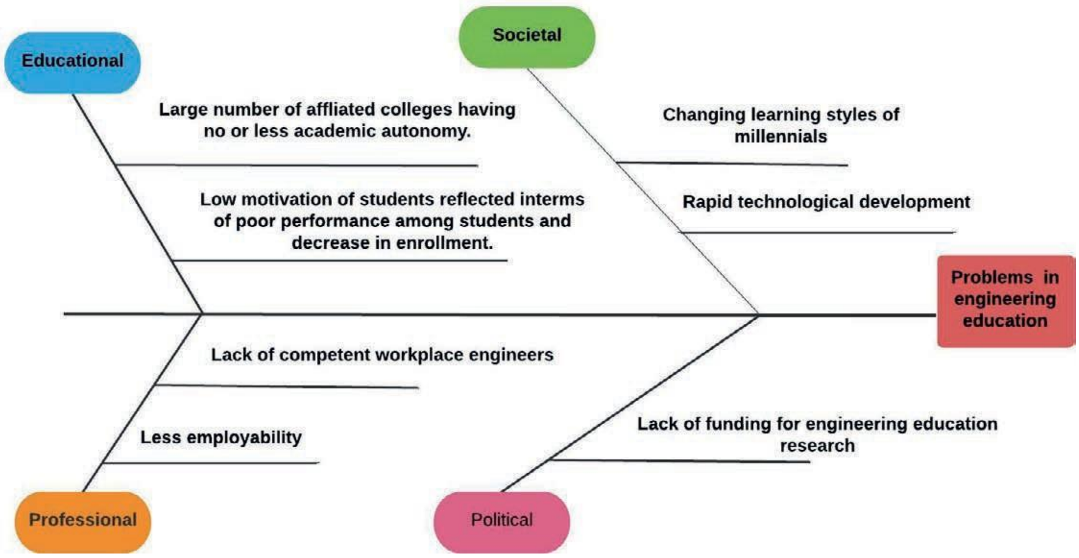

Figure 1: Fish bone diagram representing the problems in engineering education

Pellegrino & Hilton (2012) describe the competencies expected in 21^{st}-century engineer graduates and classify the competencies into three domains, namely cognitive, interpersonal, and intrapersonal, as represented in Figure 2. The educational ecosystem should offer learning experience to build the competencies among the students in all these three dimensions.

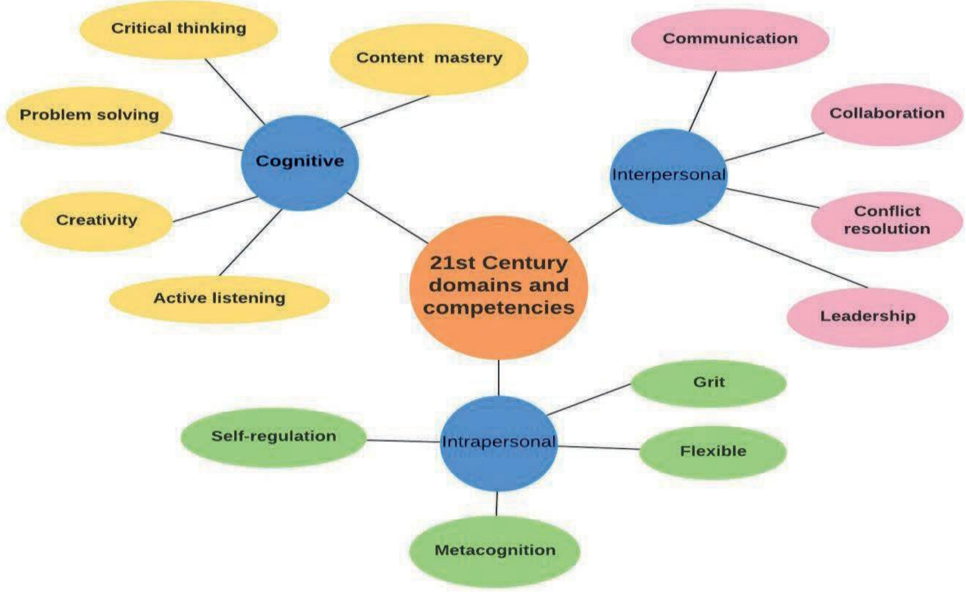

Figure 2: Competencies and skill set required by 21st century engineering graduates (as described by Pellegrino & Hilton (2012)

It is evident from the literature that shift from traditional lecture-based approach to a learner-centred approach brings a qualitative change. Instructional strategies like project-based learning (Kolmos & de Graaff, 2014), problem-based learning (Gallagher *et al.*, 1992), case-based learning (Kolodner & Guzdial, 2000), inquiry-based learning (Edelson *et al.*, 1999), and intentional learning (Scardamalia & Bereiter, 1991) are few among them which have been useful in various educational contexts as per the literature. However, the scope of this paper is restricted to study project-based learning in the context of engineering education.

According to the theory of constructivism (Perkins, 1991; Piaget, 1969; Vygotsky, 1978) and constructionism (Harel & Papert, 1991; Kafai & Resnick, 1996) every individual, constructs knowledge in his/her way, depending on the opportunities that are created around him/her. Construction of artefacts to demonstrate the learning is one of the effective ways that creates an opportunity for the learners to organize their learning as well as to engage them effectively. One such instructional strategy that encompasses an artefact as output is Project-Based Learning (PBL). PBL is a learner-centred instructional strategy that has the following characteristics

1. Projects help the learners to organize their learning.
2. Projects make learners more responsible for their learning and have autonomy over what they learn (Tassinari, 1996; Wolk, 1994; Worthy, 2000).
3. Learners shape their projects that fit their learnings and interests.
4. The construction of artefacts enables the expression of diversity in learners, such as interests, abilities and learning styles. (Grant, 2002).

Though the outcomes of PBL is encouraging but still considering PBL as an instructional strategy in the context of engineering education is still daunting because of lack of gold standard PBL framework with operationalized variables in the context of engineering.

Literature shows that there are several examples of PBL implementation in engineering education (Kolmos, A., & de Graaff, 2014; Pee & Leong, 2005) and there is a wide variation in the way PBL is implemented. Thus authors observe that there is a need for a framework that guides the instructors in the direction of

1. Considering the appropriate PBL elements based on their coursecontext.

2. To design pedagogy, activities and assessment in line with PBL elements.

Accordingly, research objectives and research question are formulated asunder:

Research objective 1- Evaluate project-based learning frameworks using graduate competencies defined by

the National Research Council (Pellegrino & Hilton 2012)
Research objective 2-Propose a conceptual framework contextualized to the engineering education system
Research question- What are the essential elements to be considered by the course instructors to adopt project-based learning as an instructional strategy in the context of engineering education?

Evaluation of various PBL frameworks (research objective 1) helps engineering educators to understand the current methods of practices, their scope, limitations, and possible new directions of research while the conceptual framework (research objective 2) helps the engineering educators to use PBL as an instructional strategy in their course.

Further sections of the paper describes about the evaluation of existing PBL frameworks considering the graduate competencies constituted by the National Research Council (Pellegrino & Hilton 2012) followed by description of elements required for each of the PBL models and finally a conceptual framework that helps educators to choose the appropriate PBL model suiting the learning context is proposed.

2 Review of Existing frameworks

The literature presents different PBL frameworks proposed for diverse educational settings. Six frameworks proposed during the period of 2002-2019 were studied, and it is observed that there exists a gap in terms of a PBL framework that can guide educators to make a choice of set of elements that are required for the use of PBL as an instructional strategy in a particular course

Existing PBL frameworks are evaluated in this section using the graduate competencies defined by the National Research Council (Pellegrino & Hilton, 2012). Elements described in each of the frameworks was mapped with the perspective of cognitive, interpersonal and intrapersonal skills and checked for the emphasis. An evaluation was done by analyzing the intent behind each of the element as defined by respective authors. Based on the match between the numbers of elements focusing on each of the skills, the emphasis was described as "high", "moderate", "low" and "not addressed". Details of the evaluation are shown in Table 1.

Table 1. Evaluation of PBL frameworks with using the graduate competencies defined by the National Research Council

References	**Elements considered**	**Authors inferences**		
		Emphasis on **cognitive** skills	Emphasis on **Interpersonal** skills	Emphasis on **Intrapersonal** skills
Thomas (2000)	1. Centrality 2. Driving questions 3. Constructive investigations 4. Autonomy 5. Realism	**High**	**Not addressed**	**Low**
Grant (2002)	1. Introduction 2. Task 3. Resources 4. Process 5. Guidance and scaffolding 6. Cooperative/Collaborative learning 7. Reflection	**High**	**Moderate**	**Low**
Ravitz(2010)	1. In-depth inquiry 2. Over an extended period 3. Student self-directed learning 4. Formal presentation of results	**High**	**Low**	**Low**
Parker et al. (2011,2013)	1. Rigorous projects 2. Quasi- repetitive project cycles 3. Students engagement 4. Teachers as co-designers 5. Scalable model	**High**	**Not addressed**	**Not addressed**

Krajcik and Shin (2014)	1. Driving questions 2. Focus on learning goals 3. Scientific practices 4. Collaborative activities 5. Learning technology scaffolds 6. Creation of artefacts	**High**	**Low**	**Low**
Larmer and Mergendoller (2015)	1. Key knowledge 2. Challenging problem or question 3. Sustained inquiry 4. Authenticity 5. Students voice and choice 6. Reflection 7. Critique and revision 8. Public product	**High**	**Moderate**	**Moderate**

1. All six frameworks emphasize more on improving cognitive skills while very less or no emphasis on inter and intrapersonal skills.
2. A single framework alone is not sufficient to cater to the need of improving competencies in all three dimensions.

The authors also observe that elements of the framework are even dependent on other factors at input, process and output stages. Thus a conceptual framework that attempts building the competencies in all three domains across the engineering program by using PBL as an instructional strategy is proposed. The following section describes the details of the proposed framework.

3 Proposed Conceptual framework

PBL implementation may be seen in three ways, namely add-on, integration and re-building. Add-on method was tried out at the course level (Yusof *et al.*, 2012; Shinde, 2014; Shinde & Kolmos,2011), while integration method (Dutson *et al.*, 1997; Todd *et al.*, 1995) at the department level by integrating the courses and re-building method at the program level (Wang *et al.*, 2017). In this paper, the authors propose a structure that has inter-related blocks and defines them as elements. The proposed conceptual framework can be used for add-on, integration and re-building modes of implementation. The proposed framework is based on Savin-Baden's five PBL models (Savin-Baden, 2007) over which the elements of the framework are mapped. Authors categorize the elements of the framework into three categories, namely input elements, process elements and output elements, as shown in the swim lane representation of figure 3.

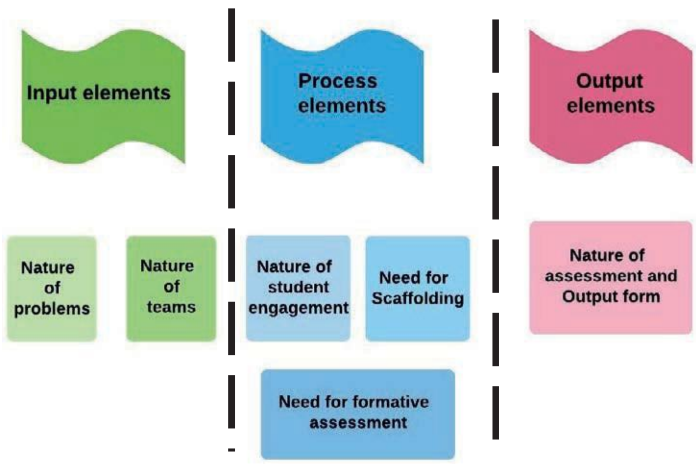

Figure 3: Swim lane diagram representing the categorized framework elements

Educators wanting to start with PBL as an instructional strategy have to choose one of the PBL models based on the expected learning outcome. Then the proposed framework guides the educators to understand the different elements to be considered at the input stage, process stage and output stage. However, all the elements are interdependent.

i) Input elements: There are two elements to be considered as at this stage: nature of the problems and nature of the teams.

Nature of the problems- This element of the proposed framework targets to emphasize cognitive skills which discuss choosing the right kind of problem suitable for the expected learning outcome. Jonassen (2000) identifies eleven types of problem namely logical problems, algorithmic problems, story problems, rule-using problems, decision-making problems, and troubleshooting problems, diagnosis-solution problem, strategic performance problems, case-analysis problems and dilemma problems and mentions that the instructors can choose these problems depending on the learning expected out of context. On the other hand, in the Saven Baden's five PBL models, every model has an expected learningoutcome.

Hence in the proposed framework, a mapping is done between the expected learning outcome defined in each of the PBL models with that of eleven types of problems identified by Jonassen (2000) such that educators wanting to adopt/adapt a particular PBL model will have clarity regarding the nature of the problems to be defined to meet expected the learning outcome.

Nature of the teams-This element of the proposed framework targets to emphasize both intra and interpersonal skills. Anchored with the learning outcome of the course, the instructor has to decide a strategy to compose a team. However, the effective team size and team formation strategy for each type of PBL model is the scope for further research.

ii) Process elements- There are three elements to be considered as at this stage which includes the way to engage students, the ways to scaffold and ways to ensure the learnings.

Nature of student engagement- During the process of using PBL as an instructional strategy, to equip students to proceed, there is a need for designing collaborative activities. The structure of these activities, further depends on expected learning outcome, nature of problems, nature of teams and nature of output forms. For example, collaborative activities may be designed to instil project management skills and communication skills. This element emphasizes equally on intrapersonal, interpersonal skills and cognitive skills.

Scaffolding- The role of an instructor in a PBL instructional scenario will change from, the role of knowledge transferor to a facilitator and has to play multiple roles. The role of the instructor changes based on the expected learning outcomes, nature of problems, type of collaborative activities designed, and expected output artefact. The need for scaffolding is to ensure that student succeeds. Scaffolding targets to address cognitive, intrapersonal as well on intrapersonal skills

iii) Assessment- Literature describes the assessment and its need. It further classifies them into assessment for learning (formative assessment) and assessment of learning (summative assessment) (Yusof et al., 2012).

Formative assessment- The instructor needs to review the status of the work and provide feedback that helps the student to improve the deliverable. The nature of the review should be constructive and genuine that motivates the students to rework and produce. Formative assessments help instructors to ensure the student's learnings, direction, steps and process being followed. This element targets to focus more on intra and interpersonal skills while less emphasis on cognitive skills.

iv) Output elements: Two elements to be considered at this stage are ‘How to assess the learning’ and ‘what to assess’?

Summative assessment: This element describes how to assess learning. In a traditional examination system, learning of a student is assessed based on the ability of the student to represent the information on paper in a stipulated amount of time, which restricts the instructor to design assessments to evaluate Higher Order Thinking Skills (HOTs). However using PBL as an instructional strategy, this problem can be eliminated. This element is an important element that connects from the nature of problems to attained learning outcomes. The authors recommend using rubrics based assessment instead of quiz-based assessment and multiple-choice questionnaires which kills the aspirations of PBL instructional strategy. This element targets to focus on cognitive skills rather than intra and interpersonal skills.

Nature of output form- This element describes about 'what to assess?'. Authors observe that the general misconception among several educators is that, the output of using PBL as instructional strategy results in a physical prototype leading to productization. Thus, through this proposed framework, authors present the possible output forms and further the educators can make a choice based on the learning outcome.

Figure 5 shows the proposed conceptual framework represented in the form of five swim lanes, each of the swim lanes represent a PBL model to which a learning outcome is associated and characterized by its input elements, process elements and output elements (represented from bottom to top).

The lane describing PBL for epistemological competence can be characterized by input elements mono-disciplinary team and troubleshooting problems/ rule-using problems/ algorithmic problems since the expected learning outcome defined for this PBL model is making students competent to apply propositional knowledge. Accordingly, collaborative activities are expected to be designed. The need for scaffolding in this model is to help students to locate authentic resources to learn propositional knowledge or technology. The role of formative assessment is to ensure the direction towards expected learning outcome. The learning outcome can be assessed on the role-play or reflections or multimedia presentation or simulation or breadboard implementation.

The lane describing PBL for interdisciplinary understanding can be characterized by input elements including mono-disciplinary team and nature of problems could be troubleshooting problems, rule-using problems or algorithmic problems since the expected learning outcome defined for this PBL model is making students understand disciplinary boundaries. Accordingly, collaborative activities are expected to be designed. The need for scaffolding in this model is to help students to clear the misconceptions and acquire skills. The role of formative assessment is to ensure conceptual clarity. The learning outcome can be assessed on the proof of concepts, kit based implementations (example includes microcontroller-based, FPGA based or DSP kits)

The lane describing PBL for transdisciplinary understanding can be characterized by input elements including multi-disciplinary team and nature of problems could be decision-making problems, design problems and case analysis problems since the expected learning outcome defined for this PBL model is making students apply knowledge and skills across the boundaries. Accordingly, collaborative activities are expected to be designed such that opportunities are created to instil intra and interpersonal skills.

The need for scaffolding in this model is to help students to learn the engineering design process, mathematical modelling, bridging the gap across the boundaries, resolve conflicts, encourage leadership qualities. The role of formative assessment is to ensure the right steps/process/ approach is followed. The learning outcome can be assessed on the mathematical model or functional prototype or simulations.

The lane describing PBL for professional action can be characterized by input elements including multi-disciplinary team or an individual and nature of problems could be design problems, strategic performance problems or dilemmas since the expected learning outcome defined for this PBL model is making students demonstrate the workplace skills. The need for scaffolding in this model is to help students to learn standard practices and learning skills. The role of formative assessment is to ensure the alignment with standards. The learning outcome can be assessed on scalable functional prototypes and portfolios.

The lane describing PBL for critical contestability can be characterized by input elements including multi-disciplinary team, or an individual and nature of problems could be research questions or research gaps or a potential market need since the expected learning outcome defined for this PBL model is making students develop new knowledge or hypothesis. The need for scaffolding is to challenge and critique the student work. The role of formative assessment is to ensure the right steps/process/ approach/methodology is followed. The learning outcome can be assessed based on a developed framework or business model or applied patent or I.P. or publications or even scalable functional prototype.

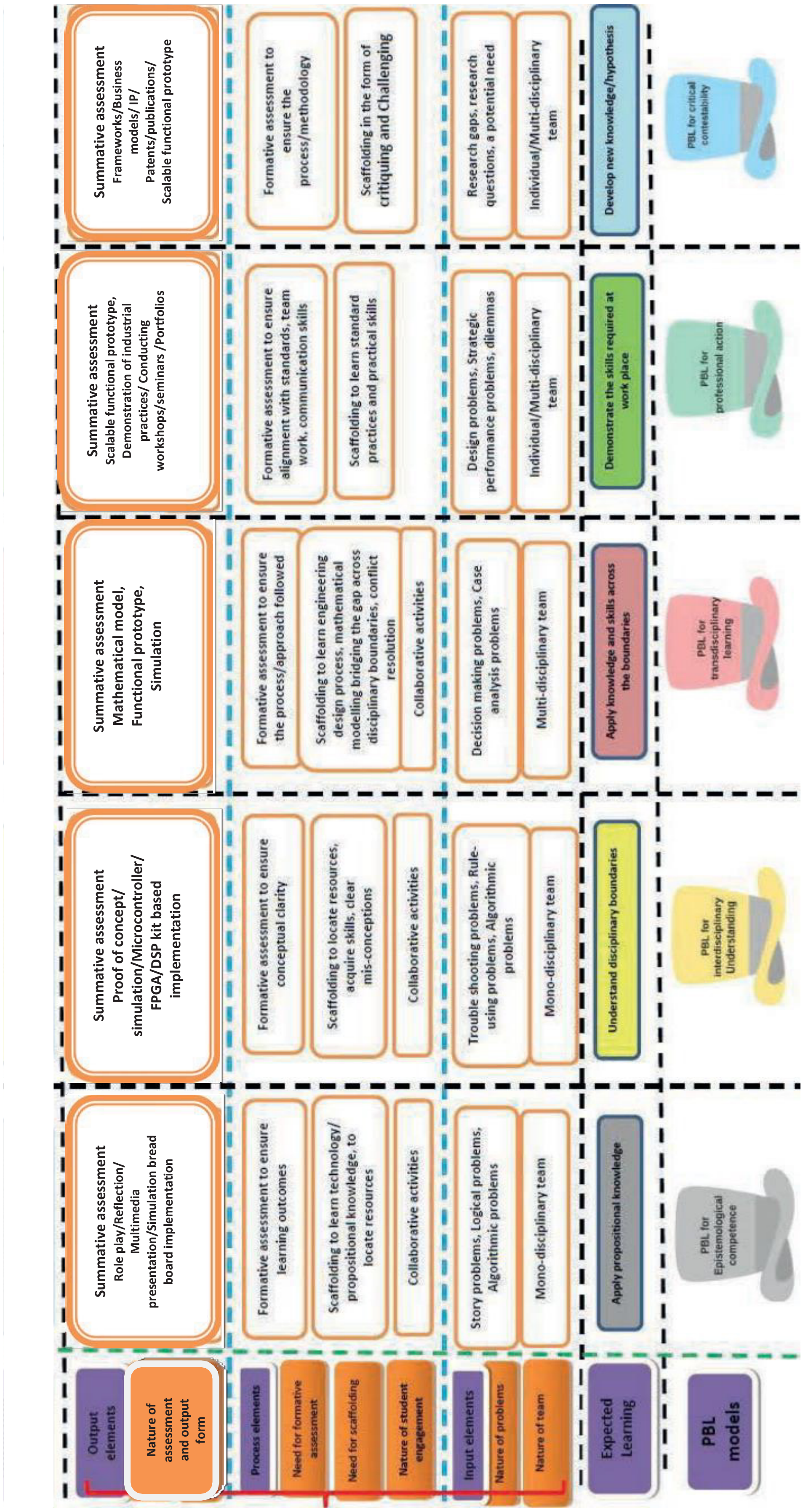

Figure 4: Proposed Conceptual framework for using PBL as instructional strategy in engineering education

4 Conclusion

Review of various PBL frameworks helped the authors to understand variations in PBL practices that are in vogue. Evaluation of existing frameworks helped to identify gap that the existing PBL frameworks do not equally focus on cognitive, intrapersonal and interpersonal skills which are required to enhance employability. Thus authors proposed a conceptual framework that adds elements at the input stage, process stage and output stage encompassing all the three skills. This paper helps educators wanting to adopt or adapt PBL in their course designs and make a well-informed decision based on the nature of problems, nature of teams, collaborative activities, scaffolding and assessments. The proposed conceptual framework is considered for the pilot study. Future work has the scope to include team formation strategies that apply to each of the PBL models.

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Issues and practical solutions in project group writing in the PBL education

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Abstract

In this paper, the problematics of the writing process in undergraduate and master's courses in the context of a problem based learning education are analysed. In this context, writing usually occurs in students' groups. The principle is that students learn together with peers under the supervision of faculty members. In this context, the report is a "tool" which the students used to advance in their learning process and communicate with group members, supervisors and censors.

Despite the main well-recognised advantages of the students' projects in the PBL education context, some recursive pitfalls are encountered by students during the report writing process. These issues can eventually hinder learnings and/or demotivate students. In this paper, it is proposed to tackle these problems by providing students, at the beginning of the project, a clear description of the report section contents and a list of common pitfalls encountered by inexperienced students in the writing process. Additionally it is recommend to provide students with a clear indication of the report assessment criteria. In this way, students are aware of the areas to put their energies on, since the early phases of the project.

To summarize, based on the experience described in this paper, it can be stated that successful learning requires that the supervisor acts both as an academic expert, which provides written and verbal guidance. While PBL education system gives more freedom of initiative to the students compared to other education systems, the student guidelines, which are recommended in this study, can be considered not so invasive and can result beneficial to the student learnings.

Keywords: Academic writing, Peer learning, Writing groups

Type of contribution: PBL best practice paper

1 Introduction

Improving the quality of the student report influences the quality of writer's thought and helps the readers to better grasp the report content (Gopen and Swan, 1990). Effort and focus should be put by both supervisors and students to make sure that the writing process fulfils these objectives while respecting all academic standards.

In the engineering field, the IMRaD format (Introduction, Method, Results, and Discussion) has emerged as the standard template for scientific writing. This format is useful for the readers that will easily find well-organized information. The IMRaD format is also beneficial to students as they can follow a document structure that can help organizing their learnings.

Project- and problem- based learning has become a popular teaching method in many higher education institutions across the world as it promotes a learning style where students can actively engage in a real work project (Graaff and Kolmos, 2003). Differently from subject oriented project work, the problem based work is characterised by the development a coherent analysis focused on specific research problem (Olsen and Pedersen, 2005). The problem work requires to formulate specific questions, to solve the problem and draw well-documented conclusions. Generally the project problem is defined by the students in dialogue with the supervisors (Dahl, 2018). At Aalborg University, during the engineering education, students carry out several projects in cooperation with researchers, industry partners and technicians to develop experimental and/or numerical activities. While exposed to this research environment, it comes natural for them to read scientific papers and develop the craft of research.

In the PBL context, the report writing during group projects is executed during an extended period of time in which the students develop their knowledge. In this context, the risk is that new and old information can be provided without uniformity. Additionally the work is carried out by several students causing inconsistency between different writing styles, nomenclatures and different language abilities. These leads to recurrent mistakes in the students reports especially among inexperienced students. Another major issue identified during the writing process is the students inability to describe the problem, to support it with previous studies and finally to draw sound conclusions and critical analysis of the project results. It becomes crucial in this context, the development of skills for giving and receiving feedback and critiquing others' work during cooperation among peers and supervisors.

In the paper, it is examined how we can improve students report writing during group work in the context of a PBL engineering education. The analysis can be considered applied to students that do not have yet reached a significant level of maturity in teamwork and reporting. The paper starts describing a common format for report writing in the PBL engineering education after the list of the main pitfalls in each sections is reported. Finally, it is proposed and analyse an assessment strategy, which can increase the motivation of students and ultimately improve their learning process.

2 Method

Some common pitfalls and mistakes can be identified during the students report writing. To tackle this problem, it is proposed to identify the main recursive pitfalls in report writing. It is also considered the possibility to describe in more details the content of each section of the project report. The IMRaD format is considered as a reference for this study because it is already the *de facto* standard in the engineering field. The report writing process is to be considered in the context of PBL engineering education where students are requested to solve a real and meaningful problem over the period of the project in cooperation with academic supervisors and industry partners.

As a solution to the problem, it is also proposed to improve the project report assessment by providing the students, clear indications on how the project will be evaluated. After, the limits and implications of this approach are discussed.

3 Results

The general report structure of a PBL Report format is similar to the IMRaD format. Figure 1 shows a comparison between the two formats. For the IMRaD format structure and contents of each section, several guidelines are available (Manterola *et al.*, 2007; Gastel and Gastel, 2013). PBL format provided in (Olsen and Pedersen, 2005) Chp.14 is a used as a reference in this study.

It is important to point out that the IMRaD and PBL report formats have developed independently in different context. According to (Meadows, 1985), the IMRad report format has been defined over the time in an evolutionary process where authors have described the typical steps of a scientific investigation in a linear manner. The PBL report format, on the other hand, has not been "officially" defined, although some requirements are usually demanded. For instance, it is important for the students to formulate specific problem questions. On the other hand, a throughout literature review of the state of the art of the technology as seen in scientific papers may be necessary. PBL report format provided in (Olsen and Pedersen, 2005) defined three main sections for the format.

From the figure, it comes evident that the IMRaD format has a higher number of sections. In particular, the analysis section of the PBL format is divided in three subsections i.e. methodology, results and discussion. The IMRaD format has a more clear division of the information reported in each section whereas the PBL format leave more freedom to students on the content organization in the analysis section.

<table>
<tr><th>PBL format</th><th>IMRaD</th></tr>
<tr><td>Introduction</td><td>Introduction</td></tr>
<tr><td rowspan="3">Analysis</td><td>Methodology</td></tr>
<tr><td>Results</td></tr>
<tr><td>Discussion</td></tr>
<tr><td>Conclusions</td><td>Conclusion</td></tr>
</table>

Figure 1: Comparison between the IMRaD format and the PBL report format described in (Olsen and Pedersen, 2005) Chp.14.

3.1 Description and common pitfalls of each report section

In this section, it is provided a brief description of each section of the report according to the IMRaD format. Additionally, based on the author teaching experience, the main pitfalls encountered by students groups in the writing of the project report are pointed out. The intent is to give to students clear guidelines at the beginning of the project.

<table>
<tr><th colspan="2">Abstract</th></tr>
<tr><td>Contents</td><td>Common pitfalls</td></tr>
<tr><td>• The abstract stands alone and includes the main sections of the report: Background, Methods, Results, and Conclusions.
• In the abstract, only specific and quantitative results should be included.</td><td>• Provide vague and not specific information on the project results.
• The background section is disproportionally long compared to the other sections.</td></tr>
</table>

<table>
<tr><th colspan="2">Introduction “Why the project was done?”</th></tr>
<tr><td>Contents</td><td>Common pitfalls</td></tr>
<tr><td>The introduction should be organized as follow:
• Background of the study with relevant literature.
• “Problem statement” and “main questions” to be addressed in the study.</td><td>• Missing relevant and authoritative references from literature. Forming a good understanding of the problem background can be bypassed, for instance if the project supervisor has already given specific indication on the problem to be addressed in the project and students</td></tr>
</table>

• Brief description of the structure of the report.	may find unnecessary to spend the time studying the relevant state-of-the-art papers. In some cases, students may believe that a background problem analysis can be a waste of time and it is better to spend the time producing more results. • *Missing work context.* This can happen when the students have not clear the connections with previous work or with state of the art. In this case, the writers leaves the readers with ambiguity and difficulties to understand the context of the project. • *The problem statement is not clear and specific*. It is likely that the problem cannot be formulated in details at the beginning of the project. Nevertheless, it is important that the students re-formulate the problem statement and research question thought the project. This exercise has the effect to keep the team in focus. • *The problem is not formulated in the early phase of the project.* In this case, time can be wasted on irrelevant tasks and activities that do not provide value to the projects.

Method "How was the study done?"	
Contents	**Common pitfalls**
• Assumptions of the study. • Accurate description of the model and/or experiments supported by relevant references and all the input necessary to solve the problem.	• *Missing important assumption, information and data that hinder the possibility to reproduce the work described in the report.* In this case, the reader, which is not aware of the details of the project, may find difficult to get the clear picture of the study.

Results "What it was found?"	
Contents	**Common pitfalls**
This section provides the description of the study findings that match the problem statement and research questions. In an engineering report, this section generally includes figures and tables that were produced during the study. Each result should be specifically commented with reference to	• *Missing description of crucial data and information.* In some cases, it is impossible for the reader to assess the validity of the results because crucial data are missing in this section. This mistake is quite common because it requires a lot of experience to identify which information should be included in the report and which can be considered not critical to

theories described in the methodology section.	form a deep understanding of the results. In a project that requires inputs from several students, it is more likely that this will happen as different students have different understanding of the subject and write different parts of the document.

Discussion "What is the study relevance?"	
Contents	**Common pitfalls**
This section should offer a broader elaboration of the single results shown in the previous section with connections between each of them as well as with other results from literature. Analytical insights, implications and the limits of the study should be commented in this section.	• *The section is completely omitted.* In some cases, it can be perceived that the project ends with the results. The writer may find sufficient to state something such as: "the results agree with the work available in open literature".

Conclusion "What are the major findings?"	
Contents	**Common pitfalls**
• Summary of the purpose of the study. • Conclusions of the study that match the research questions provided in the introduction section. The conclusions should briefly include all the study results. • Future directions.	• *Missing conclusion.* In same rare cases, students may think that conclusion are included in the results question. • *Conclusion are not well aligned with the research problem.* Readers want to see conclusions that are well connected to problem questions.

Reference List	
Contents	**Common pitfalls**
• List of articles, books and website used as a source material for the study.	• *Some key information, facts and figures are not referenced.* This can be problematic because it leaves the reader with a sense of ambiguity. • *The used reference are not authoritative.* Generally peer reviewed articles in well-recognized journals can be considered authoritative. Similar criteria should be applied to books and website.

3.2 Assessment

As suggested by (Race, 2014), it is widely accepted that the assessment is major driver for students learning and therefore if the assessment process is not done properly, it can demotivate the students or even hinder the effectiveness of the learning process. Students unfortunately often perceive the report marking criteria as not clear. This can be particularly true if the criteria is not directly communicated to the students. Other times, it happens that students come from different academic background and they are not used to the new learning model. In this context, it is important to make the assessment transparent to students so that they are made aware of the basis on which the assessment of their work ismade.

To solve this problem, a grading checklist similar to the one proposed by Felder and Brent, 2010 can be provided to the students. In this way, the students can get an idea of the criteria by which their report will be assessed since an early stage. Technical content, organization and presentation are the three major levels that the students should improve and keep under control during the writing process. A List of levels for the evaluation is provided below. A weight can be attributed to each level; in this case, the technical content is the one which is considered the most important.

- *Technical content (60%)*
  - Clear introduction and background
  - Good knowledge of the subject
  - Clear model description
  - Scientific soundness of results
  - Conclusions are aligned with problem statement and research questions
- *Organization (10%)*
  - The document included all the sections in the IMRaD format
  - There are good transitions and connections between sections
- *Presentation (30%)*
  - Grammar and syntax, easy to read and clear language
  - Document formatting, quality of the figures and tables
  - Visual consistency across the document

4 Discussion

In the paper, it is suggested that providing explicit written guidelines can help students producing more scientifically sound results. During the dialogue with peers and supervisors many of the points suggested in this paper are discussed, some points may be considered common sense and in other cases, there is not enough time during the meeting to provide accurate description about the report contents and assessment.

An advantage of the suggested approach is that it will avoid situations in which there is ambiguity or lack of clarity, however some limits in this approach can be expected. First, novice students will need to work at different levels, this can be very demanding and cause high cognitive load with the risk that the students will experience other problems. Additionally, the rigorous working framework provided by the report guidelines may hinder the creative approach required by the problem solving.

5 Conclusion

Students go through same pitfalls and mistakes when facing project report writing. This could happen especially to inexperienced students in undergraduate and master's courses when they are still learning competencies such as teamwork and report writing.

Two main strategies are suggested to avoid these issues. The first strategy consists in providing the students with clear indications of the report sections with contents and common pitfalls. The second is to inform students with the assessment criteria of the project report since the early phases of theproject.

While the PBL system leaves more freedom for initiative to students, the directions suggested in this article can become beneficial to them, increase their output and overall their learning experience.

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PBL, cognition and Social interactions – Processes and Tools to Develop Collaborative Competences

By hand and by computer – A video-ethnographic study of engineering students' representational practices in a design project

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Abstract

In engineering education there has been a growing interest that the curriculum should include collaborative design projects. However, students' collaborative learning processes in design projects have, with a few exceptions, not been studied in earlier research. Most previous studies have been performed in artificial settings with individual students using verbal protocol analysis or through interviews.

The context of this study is a design project in the fifth semester of the PBL-based Architecture and Design programme at Aalborg University. The students had the task to design a real office building in collaborative groups of 5–6 students. The preparation for an upcoming status seminar was video recorded in situ. Video ethnography, conversation analysis and embodied interaction analysis were used to explore what interactional work the student teams did and what kind of resources they used to collaborate and complete the design task. Complete six hours sessions of five groups were recorded using multiple video cameras (2 – 5 cameras per group).

The different collaborative groups did not only produce and reach an agreement on a design proposal during the session – in their design practice they used, and produced, a wealth of tools and bodily-material resources for representational and modelling purposes. As an integral and seamless part of students' interactional and representational work and the group's collaborative thinking bodily resources such as "gestured drawings" and gestures, concrete materials such as 3D-foam and papers models, "low-tech" representations such as sketches and drawings by hand on paper and "high-tech" representations as CAD-drawings were used.

These findings highlight the cognitive importance of tools and the use of bodily and material resources in students' collaborative interactional work in a design setting. Furthermore, our study demonstrates that a focus primarily on digital technologies, as is often the case in the recent drive towards "digital learning", would be highly problematic.

Keywords: PBL learning environments, design learning, video ethnography, collaborative learning, interaction analysis

Type of contribution: PBL research

1 Introduction

Science and engineering differ in important aspects (e.g. Skolimowski, 1966). Simply put, the aim of science is to produce theories, laws and models that describe some aspect of (idealized) reality. On the other hand the aim of (engineering) design is to design technical artefacts (i.e. products, processes or systems) and arrive at "artefact proposals" (Galle & Kroes, 2014). The proposed technical artefacts are human-made physical objects, but they are also intentional objects designed to perform some function in order to achieve some goals (Kroes, 2002). A design need not only consider physical and technical constrains, but also contextual constraints to achieve its intended function. Design is thus not just "applied science" and accordingly "we can't teach design like we teach science" (Bucciarelli, 2001, p. 306). Hence, as argued by Samuel and Lewis (1991, p. 314): "[analytical approaches] where there is heavy emphasis on solving problems with unique answers … will fail in engineering design problems which have no unique answers" (cf. e.g. Dym et al., 2005; Schön, 1987). As a consequence, engineering education has been criticized to actually emphasize "science thinking" and employers argue that many engineering graduates display inadequate ability to apply their theoretical knowledge in practical engineering situations (e.g. Crawley et al., 2014).

For this reason there has been a growing interest that engineering curricula should include collaborative design projects (e.g. Crawley et al., 2014; Edström & Kolmos, 2014) as engineers are expected to be able to design things and processes that can serve human needs and protect the environment. The ability to develop and design products, processes and systems and demonstrate the capacity for teamwork and collaboration have become essential requirements for an engineering degree in many countries.

One response to this call that engineering programmes should include collaborative design projects of varying length and complexity is the Architecture and Design (A&D) programme given within the frame of the Aalborg problem based learning (PBL) model. The A&D programme includes elements of architecture education, but also builds on knowledge, skills and competencies from engineering. In the Danish context this was a novel approach when the programme started in the 1990s, as traditionally the fields of architecture and engineering are separated. The creation of the A&D programme was an attempt to combine the "technical theoretical" knowledge of engineering with the "aesthetic and artistic" artisanship of architecture, to create a new interdisciplinary education.

2 Background

Given that design-based learning activities have increasingly become a key component in engineering education, there is a need to better understand students' learning processes within design projects.

The dominant empirical method to investigate *students'* design *processes* until recently to have been variants of "think-aloud" exercises with verbal-protocol-analysis (Craig, 2001) mostly done in *artificial* settings. In such studies Cynthia Atman and co-workers found that professional engineering designers made higher quality designs than students (Atman et al., 2007), senior students made higher quality designs than first year students (Atman et al., 2005; Atman et al., 1999) and that the design skills of individual students developed during their studies (Cardella et al., 2008). Furthermore, it was found that skilled designers scoped problems more effectively than less skilled or experienced designers, such as students, by considering more objects and making more transitions back-and-forth among design steps (Atman et al., 2007; Atman et al., 2008). However, it should be noted that participants in these studies have been *individual* students or *individual* professional engineers and the design has been performed within a *limited time frame* (a few hours). Moreover, the design task that the participants were asked to solve has been rather fixed and limited, i.e. the task could be described as a rather well-structured problem.

More recently, studies using different forms of ethnographic methods to investigate students in naturalistic educational settings have started to appear using audio-recordings (e.g. Gilbuena et al., 2015), video-recordings (e.g. Campbell et al., 2018; Goncher & Johri, 2015), and photos and field-notes (e.g. Juhl &

Lindegaard, 2013). Moreover design reviews involving students and more capable peers have been studied rather extensively showing the interactional work done by students and peers (e.g. Lymer, 2009; Murphy et al., 2012; Nicholas & Oak, 2018), and were also the topic of the 10th Design Thinking Research Symposium (e.g. Adams & Siddiqui, 2015).

By analysing students' drawings in an ethnographic and qualitative study, Juhl and Lindegaard (2013) explored how students use representations in their design activities. They argued that the collective production of drawings as inscriptions on paper can promote knowledge-sharing and facilitate creative processes. The drawings are seen as outputs of individual and collective knowledge. However, in their study the drawings are more or less final products, and the processes of developing these drawings are not analysed. While the focus on representations in architecture, design and engineering education is novel, it is also clear that the type of analysis omits the processual aspects of the ways the representations are made in the group, e.g. the development of a professional dialogic practice. This points to the need to analyse students' actual interactional work and to study how inscriptions are produced and used as resources in students' practice.

However, little is known about students' learning *processes*, the interactional work students *do* and the resources they *use* to complete *collaborative* design projects in *natural* educational settings as most previous studies have been performed with individual students in artificial settings or have studied design review settings and not students' actual design process. Therefore, Hultén et al. (2018) argued that there is a need to better "understand and conceptualize how novices develop and perform creative design *collaboratively*" (p. 452, italics in the original work).

With the aim of enabling studies to increase our understanding of engineering students' learning processes in collaborative design projects we have recorded a very large corpus of video data from A&D-students at Aalborg University in their first, fourth and fifth semester. Analysing parts of this video material we have previously reported on the various knowledge forms that we found were at play in students' interactions (Ryberg et al., 2020) and on students' practical epistemic cognition and epistemological development (Bernhard et al., 2019) in a design project. In this study our focus is on students' representational practices and the resources they use to collaborate and to design.

3 Methodology and setting

As mentioned previously a very large corpus of video data from students' design projects has already been recorded at Aalborg University with students from the A&D-programme. The interaction within groups during the full length of projects has been recorded using multiple video cameras. The use of multiple cameras enables access, using an unobtrusive method, to students bodily-material-interactions from different points of views and such "Big Video" technology (Mcilvenny & Davidsen, 2017) is ideal for studying students "messy" design processes "in the wild" (Hutchins, 1995).

The data analyzed in this paper is from a period 14 days into a project work where fifth semester A&D students are tasked with designing an office building for an external partner. The particular session studied is where a student group (group 3: four females, two males) is preparing to take part in a formal review session the next day. After the review session the groups have approximately four weeks left to complete their design of the building.

The interactions (Goodwin, 2018; Heath, 2016; Jordan & Henderson, 1995; Tang & Leifer, 1991) within the group and with other groups were recorded using five digital camcorders (including one body-mounted GoPro camera) during complete sessions. In this case the session lasted almost six hours. To facilitate analysis, recordings were synchronized. The still photo in fig. 1 shows how the group's interactions were captured simultaneously. This video recording is part of a wider corpus consisting of approximately 500 hours of video data from five, fifth semester, groups (three groups participated for the entire project period, while two groups decided to leave the project after the critique session).

The preparation for the review session was selected for analysis as it is what Jordan and Henderson (1995) refer to as a natural unit of analysis—limited in time and with a particular purpose. The strategy suggested by Jordan and Henderson was followed and what they refer to as an "unmotivated looking" through the video data was performed. After repeated viewings, some episodes were found to contain more interesting activities from the point of view of the research questions, i.e., parts where students made extensive use of tools and other resources in their interactional work. Particularly interesting sequences were transcribed for detailed examination of interactional patterns. The transcripts (see appendix) included in this paper were translated from Danish into English.

The study was conducted under the ethical guidelines in place at Aalborg University and at Linköping University in accordance with Danish and Swedish laws. Informed consent forms were signed by each research participant. In this paper, participants have been given pseudonyms to protect their anonymity.

Figure 1: Camera views stitched together - Overview of group space.

4 Findings

The groups in this PBL design project have their own designated workspace—resembling what architects traditionally refer to as a studio (Chance et al., 2016; Schön, 1987). In fig. 1 one can see an overview of the "open studio" group 3 are working in. The group is encircled by a fixed wall with windows, and two 'walls' consisting of whiteboards and pinboards. The student groups spend time each semester organising these studios to meet their needs for a good space to learn, work and design. This includes labelling different boards and areas of the studio for specific activities. For example, one of the 'board walls' (upper right corner of figure 1) is used for various design ideas and sketches. The opposite board wall (upper left corner of fig. 1) is used as a calendar and overview of tasks, and in figure 4b is visible a board with photographs (serving as inspiration). Two smaller tables serve as storage area for drawings and 3D-styrofoam models. In the midst of the group space is the "working table", which is littered with paper, sketches, laptops, models, iPads, bottles etc.

The general findings and analysis presented in this paper are based on an analysis of the complete six hours of video, but limited space means that we are only able to present descriptions of a few short episodes serving as illustrative examples. Similar episodes exist throughout the analysed interactions. The episodes selected for analysis have been chosen to highlight some findings related to the research questions, and more detailed transcripts of them can be found in the appendix.

As mentioned previously the students are preparing for an upcoming review seminar the next day. The students in group 3 spend the first 20 minutes eating breakfast together before starting to discuss the design tasks that lies ahead of them. This group discussion goes on for 25 minutes. When this discussion is finished (45 minutes from the start) the group split and the students start to work individually with their respective tasks. The four female students remain at the main table while the male students have walked away sitting somewhere else.

Figure 2: Episode 1:1 – Ina calls for Mette's attention to discuss a design decision.

4.1 Episode 1

As we enter episode 1:1 (fig. 2 a – d) 1 hour 10 minutes into the session, the females in the group (Ina, Heidi, Mette, and Sine) all sit working silently side by side at the main table in the group work-space. Ina is doing some sketching on her iPad (fig. 2a), but after a while she puts it away and instead she fetches two pieces (floors) of a 3D model cut out from Styrofoam (fig. 2b). She uses the floors of the 3D-model as a template for a drawing on paper. However, a design decision troubles her and she calls for Mette's attention (fig 2c) – she wants to check that it "it is not stupid what she is doing". Mette "rolls" over to Ina and by using the 3D-model Ina is working with Mette explains where she is working presently.

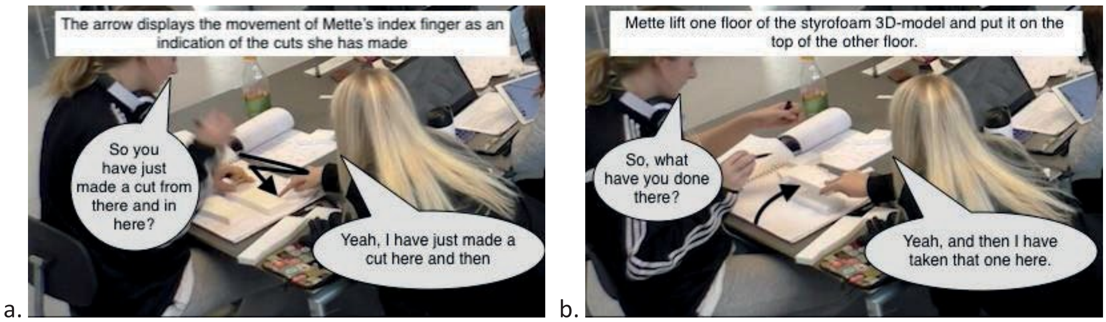

Figure 3: Episode 1:2 – Ina and Mette use the 3D-styrofoam model to reason around.

Ina and Mette continue their discussion and in fig. 3 we can see how Mette and Ina uses different pieces of the styrofoam 3D-model to reason. Ina explains some design proposals she has made. At the end of episode

1:2 (turn 20 in the appendix) Ina realizes that she has to find some details – details that are not available in the 3D-model, but in the 3D CAD-drawing on her laptop – and she “rolls” back to her place.

Figure 4: Episode 1:3 – Ina and Mette continue their discussion with use of CAD and a photo.

Ina walks over to Mette and join her in a discussion around the CAD-drawing marking the beginning of episode 1:3. The topic of the discussion is to handle conflicting design requirements – to get sun and light into offices and at the same time arrange for a walking passage without reducing space for different functions too much. Fig. 4a displays a typical discussion during episode 1:3 that circles around the CAD-drawing on Mette’s laptop. During their discussion, frequent use is made of the possibility in the CAD-programme to rotate and view the building from different angles, to view one floor at the timeetc.

However, during episode 1:3 the CAD-drawing was not the only resource made use of. In fig. 4b Ina is pointing to a picture on the board where the group keep photographs used for inspiration. Her intention is to show a similar design already implemented in reality. Some of the changes in the design that Ina and Mette have agreed on has consequences for what Sine is designing. Therefore, at the end of the episode (appendix, turn 35) Ina address Sine and ask if it is okay for them to make some small adjustment.

4.2 Episode 2

Episode 2 starts 4 hours 32 minutes into the session. In-between the end of episode 1 and the start of this episode the students have worked on finalizing different design proposals in varying constellations – they have approached particular problems in shifting subgroups of one, two or three students or as a whole group.

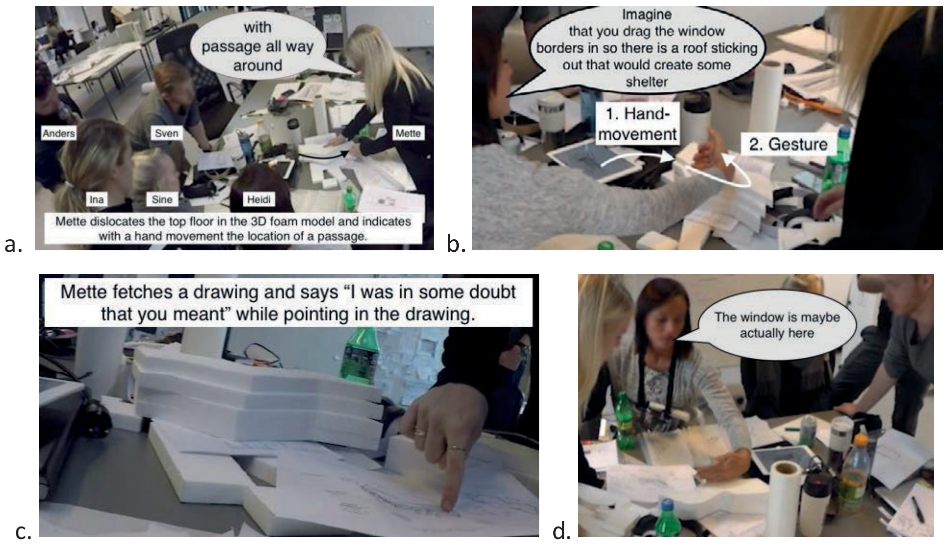

Figure 5: Episode 2 – whole group design discussion using iPad, 3D foam model, and a drawing.

Just before the episode begins, they have had lunch together, and then came together as a whole group in a self-organized peer-review session.

Immediately before the session starts the students are discussing how to address some design problems and in particular the one that troubled Mette and Ina in episode 1. Mette fetches a 3D model consisting of four separate layers ("floors") made of styrofoam. Heidi, supported by Sine suggests that the top floor of the building could be slightly shifted to complete the shape of the building and still allow for a passage.

Mette takes up Heidi's suggestion (fig. 5a) and, using the 3D model, she shows how this solution might work. As the layers of the 3D-model are not glued together she can move the floors independently to show a feasible solution. Heidi (fig. 5b, turn 37) supports Mette and propose, while first pointing at a drawing in her iPad and then making a gesture in relation to the 3D model, that by having the roof sticking out (from the shifted floor) there would be a possibility for some shelter. While Ina, Sine and Heidi discuss the proposal Mette fetches a drawing and while pointing in the drawing (fig. 5c, turn 47) she expresses that "I was in some doubt what you meant". Heidi responds by first pointing in the drawing and when making a gesture in relation to the 3D model saying "the window is maybe actually here" (fig. 5d, turns 48–51).

The session goes on for another hour with a discussion of other design proposals and how to make the presentation during the upcoming status seminar. Earlier during the day, the group had agreed on "how great [it was] when everything comes together" and how a "really … nice ping-pong we got going today". Now they agreed on their mutual trust in each other before they finished work for the day.

5 Discussion, conclusion, and implications

A first point to notice in both episodes is that talk, gestures and the use of different artefacts are intimately connected in the students' collaboration. Quite complex interactional and epistemic work can be seen in the recorded videos and in the transcript in the appendix; the still photos in figures 2–5 can only partially render the very rapid interactions intelligible. The six students are simultaneously trying to construct and elaborate a common understanding of the design problem at hand and to discuss different proposals for solving it.

In episode 1:1 we can first see Ina working on an iPad in fig. 2a. Some moments later she has shifted to make a drawing on paper by following the contours of the 3D foam model by a pencil (fig. 2b). In episode 1:2 (fig. 3) we can see how the 3D foam model is used as a tool first in Ina's and Mette's collaborative thinking and reasoning and later in episode 2 (fig. 5) by the whole group. In episode 1:3 we can see that 3D CAD-drawings (fig. 4a) are instead used as a tool for collaborative thinking and reasoning by Ina and Mette, but also that they made use of still photographs (fig. 4b). In episode 2 it can be seen that the students seamlessly made use of an iPad, the 3D-foam model, drawings on paper and gestures in their reasoning. These seamless shifts between using resources such as the 3D-foam model, 3D CAD-drawings, drawing on an iPad, formal drawings on paper, sketches on paper, pictures and gestures happen very rapidly. Still, they *seem* to be able to understand each other and follow each other's suggestions. Indeed, the fast pace of interaction and the very rare requests for clarification suggest that they share an adequate understanding of the ideas and proposals.

In the episodes, and in the transcript in the appendix, it can be seen that gestures (Goodwin, 2003) are used indexically by speakers to indicate what s/he is referring to or to demonstrate a feature of the imagined and concrete building. In the complete video recordings, although not clearly visible in the selected episodes, students also used gestures to make "gestured drawings" (Stubbs, 2006) in the air to substitute for making a quick sketch or to enhance an argument.

Throughout the session the students made extensive use of drawings, either done by hand on paper, done on various iPads, or CAD-drawings done on their laptop computers, as well as making quick sketches on paper during ongoing discussions. For example, in students' ongoing discussion of the advantages and disadvantages of the design solution with a shifted top floor, that continued for some time after the end of the interaction presented in episode 2, the students made ample use of the 3D foam model. In this discussion the foam model's 3D features, that meant it could be rotated and viewed from different angles, for example, were extensively used.

This study shows that the students used a wealth of bodily-material resources as an integral and seamless part of their interactions in their joint production of understanding and imagining. The use of bodily resources (e.g., gestures, utterances, bodily orientations), concrete materials (e.g., 3D-foam models, paper models), "low-tech" inscriptions (e.g., sketches, drawings on paper, sticky notes) and "high-tech" inscription devices (e.g., iPads and CAD-drawings) was heavily interwoven and difficult to separate. On the contrary, this study demonstrates that material resources are used by the students as epistemic tools and thus can have high cognitive value. Moreover, the use of bodily-material resources as epistemic tools transcended the boundaries of the individuals, and became tools for the group's collaborative thinking, thereby fostering connection between individual cognition and collective re-cognition (cf. Brereton, 2004; Henderson, 1999; Murphy, 2005). Thus, achievements do not only arise from individuals' thinking, but also through collaborative thinking distributed among the members in the teams *and* from the use of bodily-material resources. Indeed, according to Stahl (2013, 2016), collaborative groups build knowledge through shared understanding, co-construction, and interaction in a joint problem space.

Concurrently there is an urge that education (and society) should become more "digital" (for critical reflections, see for example: Fawns, 2019; Selwyn, 2014). As a consequence, if tools and resources are considered at all, it is common to see these as synonymous with "digital technologies". For example, at the European engineering education conference 2018 in Copenhagen Flaata and Pitera (2018) almost excused themselves for their students use of "old-fashioned" sketching and drawing by hand as they were supposed to become engineers in the "modern world". However, our study shows that a focus only on "high-tech" resources would be problematic and that we in engineering education research should rather attempt to understand how students use many and varied bodily-material resources and in engineering education encourage their use (cf. Ryberg et al., 2018; Sørensen, 2009). An apparent finding in this study is that students made ample, efficient and fluent use of gestures, sketches and hand drawings and that these procedures seems to be beneficial to the design process as different tools and resources had different affordances (see also, for example Henderson, 1999; Juhl & Lindegaard, 2013; Sørensen, 2009, pp. 190-191). It is important to note that the students did not use the "low-tech" resources because they lacked the necessary skills to use the "high-tech" resources. On the contrary we argue that the students in group 3 displayed that they were highly skilled in using digital tools, but they, in each situation, used the tools and resources they deemed to be most beneficial for the task at hand.

Indeed, more than 20 years ago Henderson (1999) in her study *On Line and On Paper: Visual Representations, Visual Culture, and Computer Graphics in Design Engineering* offered a critique of the dominant ideology that paper was soon to be a thing of the past to be replaced by the use of digital tools. In her work she showed the centrality of sketching and sketches in professional engineering work and argued that CAD lacked the flexibility needed to fully support collaborative design. In our study we can see that the students use sketches and sketching, physical models and gestures as these tools and procedures offered greater flexibility and that the students mainly turned to 3D CAD drawing when finalizing design and make more (final) formal drawings. Moreover, our results challenge that the distinction between by hand and by computer, between analogue and digital tools, should be seen as a dichotomy. Rather, our results show a blurred distinction. The title of this paper "by hand and by computer" is both a paraphrase of Henderson's title "on line and on paper" and a highlight that we see that it is essential that engineering students are trained to work "by hand" *and* "by computer" and that it is *not* a question of "by hand" *or* "by computer". Indeed, Fawns (and others) argue that we need to take a "*postdigital* perspective [in education], in which the digital makes up part of an *integrated totality*" (our emphasis, Fawns, 2019, p. 142).

In this paper we have presented an in-depth analysis of the interactions a group of fifth semester students. We will continue our studies by analysing the video recordings already made, but not yet analysed in-depth, with first and fourth semesters A&D-students.

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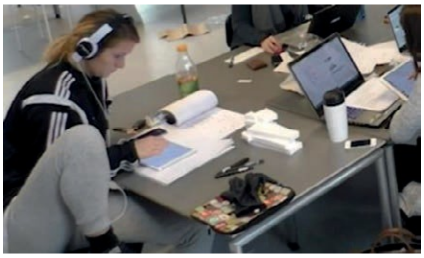
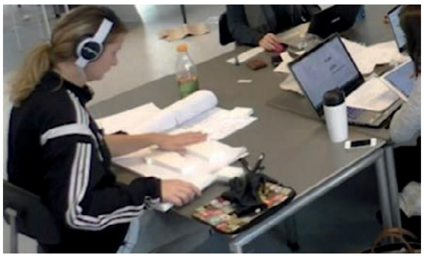
Appendix 1

(.) denotes a short pause, (x.y) denotes a longer pause in units of seconds.

Excerpt 1 01:11:14 – 01:12:14 (1 min, 0 sec.) Episodes 1:1 and 1:2

1. Ina

From 01:03:40 Ina first sits silently and make drawings on her iPad, but after a while she puts it away and instead put some layers of a 3D Styrofoam model and begin to use a pencil to trace the contours of the styrofoam model onto a paper.

2. Ina Mette? **((Calls for Mettes attention at 01:11:14))** (3.2)
3. Mette why why
4. Ina this is also two hundred (.) I just started to think about it
5. Mette Ehmmm (9.0)
6. Ina Mette?
7. Mette yes
8. Ina that is because (.) I do not know if it is stupid (.) what I am doing
9. Mette what are you doing? (4.5)

Mette moves over to the position of Ina still sitting on her chair.

10. Ina that is because I have actually changed something in it
11. Mette have you changed it?
12. Ina it is because I think
13. Heidi It is over here at the rear (.) because I think this that you (.) that you (.) well (.) here you get both (.) here you get both a terrace (.) but you also get a terrace here too

Mette has rolled over to Ina and points to the 3D-foam model.

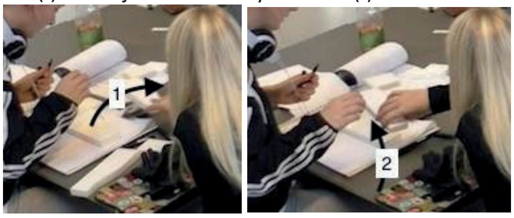
14. Ina well
15. Mette and that in the front (.) it is in this way
16. Ina well (.) so you have just made a cut from there and in here?
17. Mette Yeah (.) I have just made a cut here and then

The arrow displays the movement of Mette’s index finger indication the cut she has made.

18. Ina so (.) what have you done there
19. Mette yeah (.) and then I have taken that one here

Mette lifts one floor of the Styrofoam 3D-model and put it on the top of the other floor.

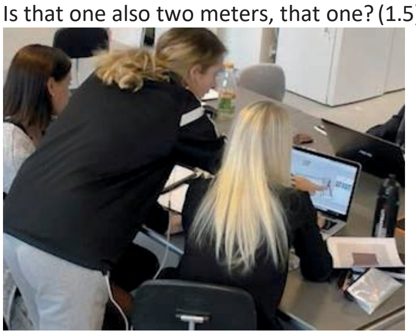
20. Mette Uh (.) now I just have to try and see (.) is it that



Mette put the first top floor of the Styrofoam 3D-model away (1) and takes the floor laying at the side and puts it on top (2).

Excerpt 2 01:19:04 – 01:20:04 (1 min, 0 sec.) Episode 1:3

21. Ina Is that one also two meters, that one? (1.5)



Ina points to the screen while asking if “that one also [is] two meters”?

22. Mette no no (.) not there
23. Ina well (.) well (.) okay (6.1)
24. Ina that is because (.) you go out right here (.) then one go around around around and in there (.) that is around (.) and then it is (.) I have tried to make a footbridge

As Ina is saying “go out right here, then one go around around around and in there” her index finger walks around the drawing of the building demonstrating what she means.

25. Mette yes (.) and so it is too
26. Ina but it of course (.) requires that there is also a whole floor free outside at the walk (.) u::m
27. Mette yes (.) here
28. Ina Yes (.) but it might well (.) because try not to see them here too

Ina turns around and look at the board with the photographs.

29. Ina if you say there are windows all round (.) right too

Ina points to a photograph while talking about "windows all round".

30. Ina and then (.) if you say that there are open offices on the other side, (.) so that if that was the case (.) such that light came in gradually through the office

Ina illustrates with a gesture how light passes in.

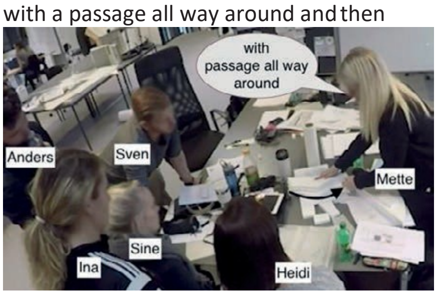
31. Mette U::m (.) that can one certainly do (.) you can also see how narrow that passage is (.) it is right in the middle there

While stating how "narrow that passage is" Mette is pointing to a photograph.

32. Ina well
33. Mette there is not very much that is there
34. Ina Well (.) okay **((Both Mette and Ina turn to the computer again))** (10.6)
35. Ina Sine, do you think it is okay for us to make some small adjustments, without

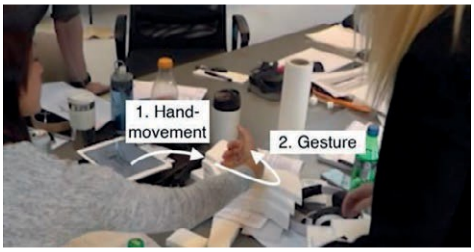
Excerpt 3 04:31:55 – 04:32:28 (33 sec.) Episode 2

36. Mette with a passage all way around and then



Mette dislocates the top floor in the 3D foam model and indicates with a hand movement the location of a passage.

37. Heidi but I also think (.) what if you now (.) imagine that you are dragging that (.) then you could also imagine that you could drag the window borders in (.) well so there still is a roof sticking out that would create a possibility for some shelter

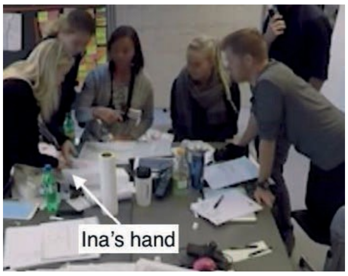


Heidi first points at a drawing on the iPad, then moves her hand to the 3D foam model and turns her hand to make a gesture.

38. Ina yeah
39. Sine yeah precisely

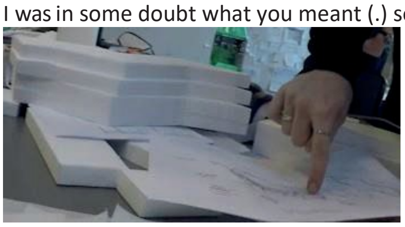
Mette goes to a table on the side and fetches a drawing.

40. Heidi for example (if one had it here)
41. Ina that could also work
42. (1.9)
43. Heidi yeah but **((Points to the 3D-foam model))**
44. Ina Is it
45. Heidi Here (.) here is the window (.) but there is still a roof here for example and then you actually have a room up here **((Points on the 3D-foam model))**
46. Ina yes (.) and it was actually here



Moves closer, leans forward, and points on the 3D-foam model.

47. Mette I was in some doubt what you meant (.) so with window borderson

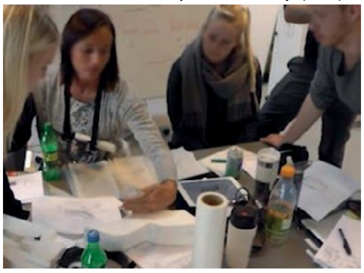


Points in drawing.

48. Heidi eh:: yes if one imagines something there also

Heide points to the drawing and Sven makes a gesture with his right hand

49. Sven (if) you to pull it back
50. Ina but you keep the shape
51. Heidi the window is maybe actually (0.6) here



Makes a gesture in relation to the 3D-foam model.

Design-Based Research: Students building workplace skills in a new educationalmodel

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Abstract

This research paper continues a longitudinal implementation of a design-based research (DBR) study and implementation for a new co-op centric educational model. Two iterative cycles take place simultaneously in this modified DBR study and interface to provide knowledge to one another. One cycle is the design of a new program; the other cycle is the research study. In this study, the research cycle includes literature review, data acquisition, analysis, evaluation, and findings. Out of the findings come recommendations for continuous improvement in the program design.

In this paper, the new model as well as the research method is described. The data analysis results in findings for the program regarding student attainment of the workplace skills. It identifies several gaps between the program's perceived importance of skills and student- identified importance of skills. These gaps provide input knowledge to the program. More findings are presented and future steps for both the program design and the research study are recommended. The findings of the research are from the first cohort of 19 students and will feed back into the program for the second cohort of 50 students, which starts in August 2020.

Keywords: Design-Based Research, PBL, Workplace Skills, Co-op, Program Development

Type of contribution: PBL research

1 Model Description

Characteristics from two "emerging world leader" programs have served as the inspiration for this new model. The programs, as recognized by a 2018 MIT report (Graham, 2018) are Charles Sturt University (Australia) and Iron Range Engineering (Minnesota). Charles Sturt is a co-op based model where students spend an initial period on campus and then do co-op (long-term internships) work placements and on-line learning to degree attainment (Morgan & Lindsay, 2015).

Similar to Denmark's PROCCED-2-WORK motivations identified by Kolmos *et al*. (2018), the development of this new model seeks to close the identified gap between education and the skills needed in the engineering workplace (Johnson *et al*., 2018). Over the past few decades, the gap has been increasingly identified *through* several international professional organizations like the Royal Academy (Spinks, Silburn, & Birchall, 2006), the National Academy of Engineering (National Academy of Engineering, 2004), the McKinsey Global Institute (Mourshed, Farell, & Barton, 2013), and the American Society for Engineering Education (American Society for Engineering Education, 2015); *through* several prominent publications (Sheppard, Macatangay, Colby, & Sullivan, 2009; Hasse, Chen, Sheppard, Kolmos, and Mejlgaard, 2013; Martin, Maytham, Case, & Fraser, 2005; Almi, Rahman, & Purusothaman, 2011; & Lindsay & Morgan, 2016); *through* accreditation bodies like ABET and EUR-ACE; and *through* political processes such as European Bologna. The adapted design-based research (DBR) design process, described later in this paper, also provides motivation for this model development through its iterative design simultaneously identifying practice needs leading to model improvements and contributing to the body of engineering education knowledge for the highest impact on preparedness of students for engineering professional practice.

Iron Range Engineering has developed curricular strategies that deliver a graduate with a technical, professional, and design competence balance (Johnson, 2016). In the new model, students finish lower- division pre-engineering requirements at a two-year college in the U.S. After which, they transfer into the program for a four-month on-ground experience where they develop the self-directed learning and professional skills needed to thrive in a co-op placement. Upon completion of this term, students enter 24 months of co-op placement/on- line learning, returning to the institution after 12 months and 24 months for one-week

examination periods (See Figure 1).

Figure 1. Co-op Program Model

The reasons for the development of the new program include a further desire to develop work-based competences during the education, empower students to use employment to help fund their education while gaining recognizable experience, and to take advantage of the variety of emerging technologies for on-line learning. Another motivation is to increase access to the engineering profession by designing it specifically for community college students which bring a wider demographic diversity than the university counterparts (American Association of Community Colleges, 2020).

In August of 2019, the first 20 students completed the engineering development phase and entered the co- op phase. 50 students are expected to start in August 2020 and 30 more in January 2021.There are many parts to the description of the new program; parts relevant to this research question are described below.

1.1 Bell Academy (The engineering development phase)

The Bell Academy is an on-site, intensive experience focused on the development of the individual in four domains: design, technical, professional, and career-search.

Design learning happens with engineering projects (from industry clients) serve as the central component to the student experience, as is done in the Aalborg University (Denmark) model of project-based learning (PBL) (Kolmos, *et al.*, 2004) Student engineers take four, one-month design cycles. During these cycles, they practice an iterative engineering design process progressing from problem definition through scoping, research, ideation, modeling, testing, and design evaluation; all while making several verbal presentations and going through several iterations of written technical documents. To promote multiple team experiences, individuals left their design team for one cycle to join a new group on a different design with a different client, returning to the original team and to finish the original project.

Technical learning occurs in the Iron Range Engineering model where students take 32 one- credit courses (16 core, 16 advanced elective) (Ulseth, 2016). 8 of these courses take place in the Bell Academy as students undergo a scaffolded experience in 4 one-month blocks (2 courses per block). The first two courses are similar to the traditional model of learning that students have experienced. In each successive block, support is removed as they transition towards being managers of their own learning, taking on more responsibility in the process. Students write learning plans; develop questioning techniques; accumulate knowledge with an eye towards long-term retention; apply engineering principles to open-ended problems; and use metacognition as a way to promote knowledge transfer (Johnson & Ulseth, 2015).

Professional learning happens across multiple levels. Responsibility is modeled and practiced from start to finish as timeliness, respect, dress, and language are all made explicit with continuous feedback coming from faculty and staff. Teamwork skills are provided in seminars and practiced in design teams. Mutiple weekly workshops address topics: inclusion, ethical action, leadership, reflection, management, happiness, life-work balance, overcoming adversity, and communication. Each week students write one-page learning journal entries, most of which are reflective prompts from some aspect of professional learning. Career-search learning happens through several iterations of the "*jobs package.*" In this evolution, students prepare a cover-letter and resume for a posting they have found and would ultimately like to apply for.

Faculty members give them feedback on their submissions. Students then undergo a mock phone interview for the position, receiving feedback on their performance. The next step is an in-person live interview. Here, students are interviewed by a panel of faculty and other students. Thus, they not only receive performance feedback but can learn from the successes and failures of others and the process of giving feedback. Finally, students send thank-you communications and receive feedback on the substance and form of this communication. Figure 2. is a graphical depiction of the *jobs package* elements.

Figure 2. Bell program job search graphic

1.2 Co-op phase

During the co-op phases, students work 40 hours per week as engineering interns for a company or organization that employs engineers. The Bell program employs “facilitators” who are bachelor’s or master’s-educated engineers with engineering experience (Ulseth & Johnson, 2018). The facilitators are the connection between the program and student and between the students and their company supervisors. Each week, the student and facilitator have live conversations over computer or telephone addressing work experiences, learning opportunities, continuous improvement, and result in much reflection. In addition to the conversations, students spend ten to twelve hours per week completing school-related work. Six of the hours are spent completing technical learning courses taught by the program’s PhD professors. The other four to six hours are spent in on-line professional development workshops, writing technical design papers, and completing written reflections on the wide variety of learning experiences taking place on the co-op placement across the professional, technical, and design domains.

After one year, students return to campus for a one-week period where they undergo a variety of technical examinations and give multiple professional presentations in both a Ted-talk type format and traditional engineering presentation format. This exam period happens again 24 months after the Bell Academy and immediately preceding graduation.

1.3 Accreditation details

The Bell program has received accreditation as an extension to its parent program’s (Iron Range Engineering) current accreditation. The program and student learning outcomes are exactly the same as the parent project-based learning program which has twice been accredited in its ten-year existence. The outcomes are extremely well aligned with ABET outcomes. The new program obviously has a different delivery modality, but the standards of student outcome achievement are the same.

2 Modified Design- Based Research Method

As the curricular development and study of the PBL program began in 2016 (Johnson *et al.*, 2018) an appropriate design and research methodology was needed to guide the development work. Design-based research (DBR) was adopted for the methodology (paee paper) for the development work to 1) address learning theories, 2) to study learning in context, 3) to develop measures of learning, and 4) to contribute to new designs and learning theories (Reimann, 2011). The curricular work incorporates the four phases of DBR identified by Kolmos (2015), as illustrated below, with elements for consideration.

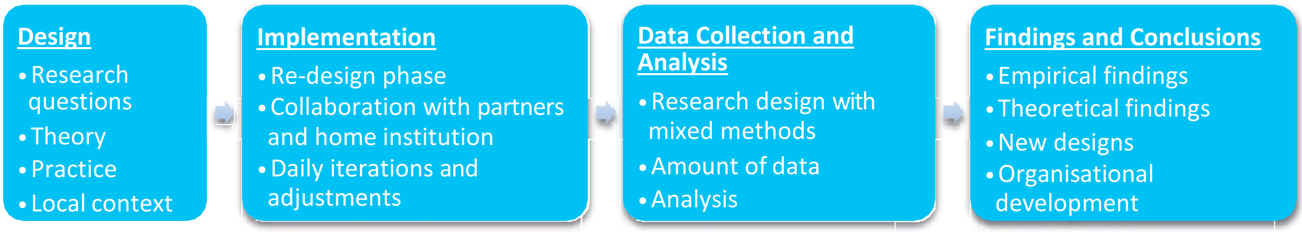

Figure 3. DBR Phases

Andriessen's (2007) dual purpose of DBR model was combined and adapted with the four phases to create the Adapted DBR Process Cycle shown in Figure 4. This cycle adapts Andriessen's streams of Knowledge and Practice as Research Design and Program design, respectively. The focus of cycle is *program design* through *progressive refinement* of 1) the problem statement; 2) defining the design and learning objectives; 3) planning (project management) of the curricular design; 4) development of the curricular ideation and selection of a design for initial implementation; and 5) ultimately a continuously reformed model with a curricular model improvement process. The *research design* focuses on establishment of 1) the research questions; 2) identify the learning theories applicable to the research work; 3) design of the research work that influences the curricular implementation and improvement; and 4) ultimately to disseminate what is learned and add to the body of knowledge on engineering education.

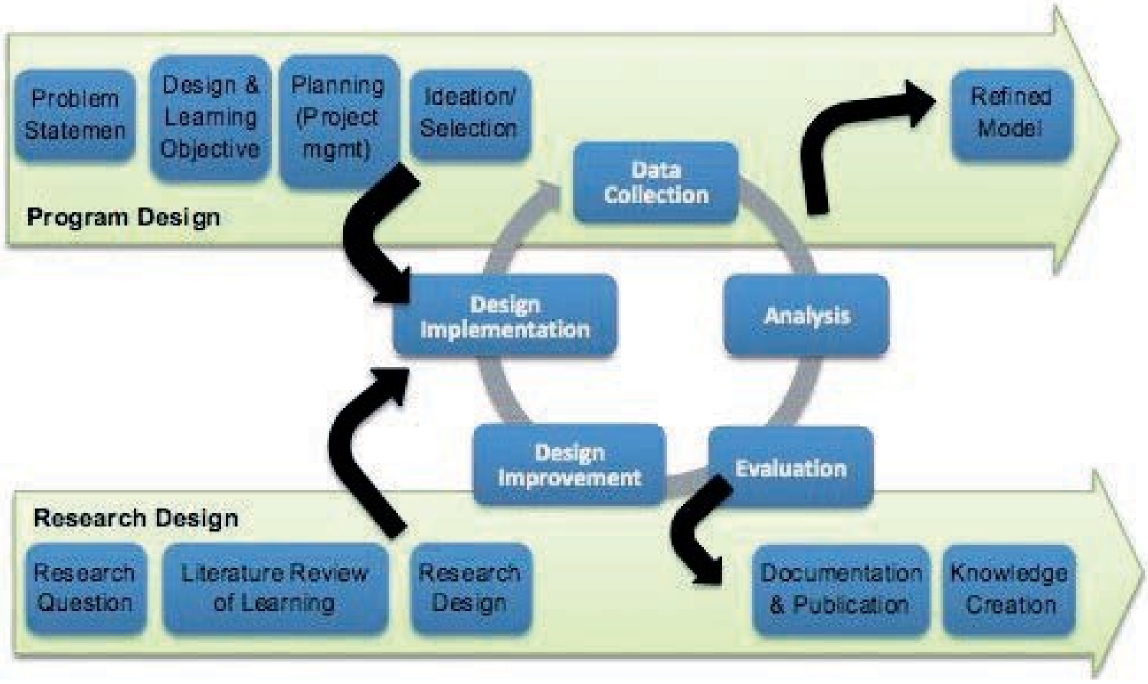

Figure 4. Adapted DBR Process Cycle

Previous iterations of the cycle have been completed on how:

- curricular elements were developed (Johnson *et al.,* 2018)
- students and faculty members viewed the new curriculum (Ulseth & Johnson, 2018).
- students experienced the attainment of their first co-op placement (Rogalsky *et al.*, 2020)

The research question for this iteration of the DBR focuses on the student preparation for their first co-op placement through the acquisition of engineering workplace skills. The adapted DBR process cycle is completed through the collection of the student experiences and inputs and subsequent analysis evaluation, program improvements will be identified and implemented into the program design.

3 Research Study

Research Question: How do Bell program student engineers acquire engineering workplace skills in preparation for their first co-op placement?

Data Collection: Content analysis is the method of qualitative research used in this project. The steps of the analysis are listed below with descriptions of the steps taken by the authors of this paper:

1) Create a list of texts to explore. The Bell program staff created six reports during the first Bell Academy. A report was written at the conclusion of each of four time blocks during the semester. Further, at the conclusion of the Bell Academy, a summary professionalism learning report was prepared as well as a similar report for design learning. During their time in the Bell Academy and on co-ops, students write 2-3 one-page learning journal entries per week. One such entry after students began their co-op placements had the following prompts: If *workplace skills are those skills you need to do your job well, list as many as you can think of that you are using in your co-op. Pick the 3 most important from this list. List the activities at IRE that helped you build these skills before your co-op.* This learning journal entry will serve as the seventh document to be explored.

2) Consider how texts will be accessed with attention to linguistic or cultural barriers. Researchers exist in close contact with the program thus limiting most linguistic and cultural barriers.

3) Acknowledge and address biases. Whereas the action research is expected to have little impact on step 2 above, this step has more to consider. Being intimately involved in the design and implementation of the program provides much opportunity for biases to exist. The authors acknowledge the biases and will seek to let the text of the documents speak rather than seeking to create personal interpretations.

4) Develop appropriate skills for research. The authors are recent PhD graduates of Aalborg University where they received training and practice in performing qualitative research.

5) Consider strategies for ensuring credibility. The authors used triangulation of the data across documents and to the literature, where appropriate.

6) Consider ethical issues (e.g., confidential documents). The documents are not confidential. There are no distinguishing characteristics that connect any of the data to any individuals. The authors have permission from the Bell program to undertake this analysis and are expected to feed the results back to the program for continuous improvement as is essential in design-based research.

4 Analysis

Bowen (2009) considers pattern recognition in the documents as a method to identify themes and categories to produce empirical knowledge and understanding. The researchers applied this scheme to the six report documents (data set one) from the educational program. Then used the anonymous student learning journals (data set two) to corroborate findings across the two data sets, seeking convergence.

Each time a category was mentioned in either a report or a learning journal a tally was counted. Following are tables displaying the most frequent categories identified and the number of cites (tallies). This is done for both the skills attained and the learning activities cited for skill building.

Table 1. Most frequently skills identified in report content analysis. (Data set one - six reports).

Skills from Reports	# of Cites
Job Search Skills	12
Design Work	12
Presenting	10
Interpersonal Communication	9
Time Management	5
Professional Dress	5
Responsibility	5
Safety	5

Table 2. Most frequent activities identified in report content analysis. (Data set one - six reports).

Activities from Reports	# of Cites
Design Project	9
Jobs Package	8
Workshops	7
Feedback	5
Career Fair	4
Technical Courses	4

Table 3. Most frequent skills identified in student journal content analysis. (Data set two - 16 student entries).

Skills from Journal Entries	# of Cites
Interpersonal Communication	11
Time Management	8
Attitude/Humor/Awareness/ Persistence/Perseverance/ Focus/Adaptability	8
Technology Use	6
Writing	4
Technical Knowledge	4

Table 4. Most frequent activities identified in student journal analysis. (Data set two - 16 student entries).

Activities from Journal Entries	# of Cites
Design Project	12
Workshops	10
Presenting	8
Technical Courses	6
CIOPS - Open-ended problem solving activity	6
Team Communication	4

Table 5. Most important skills identified in student journal analysis. (Data set two - 16 student entries).

Skills	Student/Most Important
Interpersonal Communication	6
Time Management	5
Attitude/Humor/Awareness/ Persistence/Perseverance/ Focus/Adaptability	5
Document Management	3
SDL	2
Data Analysis	2

5 Discussion of Findings and Future Steps

The perspective used in this discussion is that importance is related to the number of times cited in the documents that were analyzed. While this relationship is not absolute, it is the perspective being used for this research. As the program considers the findings for future design improvements, additional perspectives should be considered.

There are comparisons to be extracted from this data. The first comparison (*comparison 1*) is to consider the importance that the program puts on skills vs. the importance that students in the workplace put on skills. This comes from comparing the data in Table 1 and Table 3. There is alignment on the skills associated with interpersonal communication and time management. The program identifies emphasis on design work, presenting, professional dress, responsibility, and safety. These categories did not elevate to top importance for students. Whereas, the students identify emphasis on technology use and writing, which did not elevate to the top for the program. The students identified a set of personal attributes that they found important: attitude, humor, awareness, motivation, persistence, perseverance, focus, and adaptability. The researchers combined these all together into one category which rose near the top in student-rated importance. The program's top-rated category was job search skills. It is not surprising that students in the workplace doing their current work did not mention job search as an important daily skill. Finally, the students identified technical knowledge as important. While this skill did not rise to the top of the analysis in the program's reports, technical courses make up more than 50% of the curriculum and was not the focus of the reports.

Comparison 2 is drawn between the emphasis put on skill importance vs. the number of times the activities were cited in building those skills (Table 1 and Table 3). From the program perspective (reports), there was alignment between skill importance and activities in the areas of design, job search, and workshops/feedback to develop skills such as presenting, interpersonal communication, and time management. Areas for closer attention by the program could be analyzing the time emphasis in workshops and feedback on the skills desired. For example, does the time emphasis align with the desired outcome of safety skill importance?

Comparison 3 looks at the learning activity importance as cited by the program vs. the students (Table 2 and Table 4). The similarities in importance arise in the areas of design project work, workshops, and during technical courses. A highlighted point of importance here is that it appears both the program and the students recognize that skills beyond technical competence are built during the technical course execution.

Areas of difference include the program's emphasis on feedback and the job seeking. Feedback is one-on- one and not overly explicit to students; they likely wouldn't see it as an activity. Job search, as mentioned earlier, is an essential part of the Bell Academy, but time is not spent on workplace skills. The important differences to highlight that can bring value to the program design are noting and analyzing the activities that students found important, but were not elevated by the program in the reports: presentations, open- ended problem solving activity (CIOPS), and the act of team communication.

Comparison 4 addresses the "most important" skills identified by students. In addition to the researchers counting the references to each of the skills mentioned by students in their learning journal entry, the students were specifically asked to identify the most important skills (Table 5). Comparing this list to the overall consideration of skill value by the program (Table 1) and time spent developing skills during learning activities (Tables 2 and 4) can highlight additional value. Six skills are listed in this table. Three have already been highlighted in this discussion. The additional three might bring added value to the analysis. They are data analysis, self-directed learning, and document management.

These skills did not rise to the top in the program's reports, but are deemed important by some of the students. This provides an opportunity for the program to evaluate the importance of the skills, evaluate the time spent developing the skills and consider program design changes as a result of this analysis.

5.1 Input from the findings to the design improvements for the program

From *comparison 1* (skill importance between program and students):

The program should consider the emphasis being put on writing and presenting. Perhaps a little less emphasis on presenting and a little more on writing.

Students identify technology skills as being of high importance, the program should evaluate the amount of time spent in developing these skills and consider increasing it.

The program should identify the set of personal attributes the students found important (attitude, awareness, persistence, etc.) and specifically address them with students during the Bell Academies.

The program should analyze the skills they emphasized but the students did not find important such as safety and professional dress. This analysis could result in the program either deciding more time emphasis is needed or less time emphasis is needed in the design of the upcoming Bell Academy training sessions.

From *comparison 2* (program skill vs. learning activity importance):

The program should analyze their intended importance of skill development vs. the time spent on feedback and in workshops to achieve desired alignment. This could be particularly true for skills where there appears to be misalignment in importance between the student and the program (for example: writing).

From *comparison 3* (program learning activity importance vs. student learning activity importance):

The program should consider how the students found value in the activities associated with presenting, open-ended problem solving, and communications with team members. These considerations could result in design improvements to the program through more explicit skill development emphasis or increased time emphasis in these areas.

From *comparison 4* (student identified "most important" skills vs. program skill and activity importance):

Three new skills previously not identified as important in the analyses were identified: document management, self-directed learning, and data analysis. This provides an opportunity for the program to determine the value of these skills which are deemed valuable by students who have entered the workforce. The program can then consider design improvements as appropriate.

5.2 Knowledge creation

Design-based research is predicated on using the results of the research to provide input to future iteration of the program design as well as providing knowledge to the greater audiences. The section above explains the inputs to the future design of the program. The greater external audiences would include other academic programs looking to design learning experiences for the development of workplace skills, researchers looking to understand the student view of skill importance in the workplace, industry personnel seeking to understand workplace skill development in the engineering education environments. From the data analysis, input to external audiences can be seen through the following:

- Students indicate the following workplace skills are valuable while working in industry on internship-type assignments: interpersonal communication, time management, personal attributes (such as attitude, motivation, awareness, perseverance), technology use skills, writing, technical knowledge, document management, self-directed learning, and data analysis.
- There is both alignment and misalignment between what a program intends in skill importance and what the students view as important. These alignments and misalignments can be identified and studied both for greater understanding and for program development.
- There is also both alignment and misalignment between the learning activities intended for skill development and the perceived importance of the skills. Again these can be identified and studied. This paper does that for the skills identified by this program and its students.

5.3 Future steps for the research

As stated earlier this modified DBR study is one in a long series of research studies on the development of the Iron Range Engineering Bell program. The particular focus of this paper on the importance of skill development and associated activities will provide essential information into the design of the next iteration of the Bell Academy. This research will be repeated in one year after 50 more students complete a Bell Academy and are months into their work placements. The results would identify the efficacy of the design improvements that came from this work as well as identify emerging needs for improvement and could delve deeper into understanding meaning through the use of direct quotes and citations. Further, DBR can be applied to other aspects of the program's design such as the technical learning or design learning experiences of the students.

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Assessment of Collaborative-Problem Solving Competency in Engineering Education: A Systematic Literature Review

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Abstract

The industry's need for professionals with Collaborative Problem-Solving(CPS) competency is well-established in the current era. CPS encompasses competencies on both social and cognitive dimensions. The Program for International Student Assessment (PISA) and Assessment of 21st-century skills (ATC21S) have proposed assessment frameworks for standardising the assessment of this skill. The PISA standardised test was administered to 15-year old students from OECD countries and has identified the behavioural indicators that students exhibit when they solve problems, collaboratively. The students collaborated with computer agents using digital platforms as a means for communication.

Engineering problem-solving (EPS) commonly entails solving problems including design problems, troubleshooting problems, system-analysis problems and decision-making problems. Ill-structuredness and need for extensive collaboration are some of the defining features of these problems. In engineering education, generally, students solve domain-specific problems mostly through in-person interactions. There have been several successful attempts to introduce these problems in the undergraduate engineering curriculum. However, the student assessment of these problem-solving experiences is generally restricted to the outcome variables, i.e. the final solution. The process variables like types of knowledge pooled or quality of social interactions that lead to the solutions are seldom considered.

The proposed work answers the research question, "What cognitive and social outcomes of engineering problem-solving are relevant for assessing Collaborative Problem-Solving competency in Engineering Education?" To answer the research question, a systematic literature review (SLR) is adopted. Though EPS includes four types of problems, this article will focus only on design problems. The authors hope that the outcome of this review will help in designing the assessment of collaborative engineering problem-solving by considering process variables as well.

Keywords: collaborative problem-solving, engineering problem-solving, cognitive domain, social domain, systematic literature review

Type of contribution: Review/ conceptual paper

1 Introduction

The Washington Accord, which is the international agreement signed by the Engineering Education accreditation bodies of different countries ("Signatories » International Engineering Alliance," n.d.)., mandates the development of 12 competencies: engineering knowledge, problem analysis, design and development of solutions, investigation, modern tools usage, societal and environmental implication, ethics, teamwork, communication, project management and finance, and life-long learning in the context of solving complex engineering problems (Accord, 2013).

The first five competencies are referred to as technical competencies and the latter seven as professional competencies (Passow & Passow, 2017; Johnson & Ulseth, 2014). Engineering educators have been traditionally focusing on designing curriculum for developing the technical competencies with some attempts in training undergraduate students in the professional competencies (Walther, Kellam, Sochacka, Radcliffe, 2011). There is growing discontent in the industry with how engineering curriculum has been disproportionally leaning towards technical competencies. At the end of four years of engineering study, when our engineers' knowledge, skills and attitudes are put to the test in solving workplace problems(Jonassen, Strobel, & Lee, 2006), they are left wanting in the professional competencies (Patil & Codner, 2007, Brunhaver et al., 2018; Passow & Passow, 2017). Professional skills like communication and collaboration are also referred to as social skills(Nguyen,1998).

Several research studies have identified the essential workplace competencies as complex problem-solving, critical thinking, communication, collaboration and teamwork, leadership, systems thinking, among others. Generally, these competencies are also referred to as 21st-century skills, and their taxonomy has been proposed by National Research Council, USA (NRC) as cognitive, intrapersonal, and interpersonal domains (National Research Council, 2013).

1. Cognitive skills: problem-solving, critical thinking, systems thinking
2. Interpersonal skills: complex communication, social skills, teamwork and collaboration, cultural sensitivity, dealing with diversity
3. Intrapersonal skills: Leadership, self-management, time management, self-development, self-regulation, adaptability, executive functioning

The focus of the proposed work is on the competency of collaborative problem-solving (CPS) which lies at the cusp of cognitive and social / interpersonal dimensions. Though problem-solving was originally seen as an individual task, the changing nature of workplace problems, increasing complexity of technical systems, multi-disciplinary knowledge requirements, necessitates a need for collaboration in problem-solving (Fiore, Graesser, & Greiff, 2018). These skills are required for successful performance at workplaces and are mandated by several accreditation bodies (Jonassen, Strobel, & Lee, 2006; Jang, 2016). A few noteworthy studies on CPS are by Organisation for Economic Cooperation and Development's (OECD) Program for International Student Assessment (PISA) (Graesser, Fiore, Greiff, Andrews-Todd, Foltz, & Hesse, 2018; OECD, 2013), Assessing and Teaching 21st Century Skills (ATC21S) project(Griffin, 2017) and Macrocognition in Teams model (Fiore & Georganta, 2017).

If collaborative problem-solving experiences are to be included in the engineering curriculum we need to identify what cognitive and social dimensions of collaborative problem-solving are relevant to engineering problem-solving. This is articulated through research question is "What cognitive and social outcomes of engineering problem-solving are relevant for assessing Collaborative Problem-Solving competency in Engineering Education?" To answer the research question, the methodology of systematic literature review (SLR) detailed by the research question, a systematic literature review (SLR) detailed by Borrego, Foster & Froyd (2014) is adopted. Though Engineering Problem Solving (EPS) includes four types of problems viz. troubleshooting problems, system-analysis problems and decision-making problems, this article will focus only on design problems. The authors hope that this list of cognitive and social outcomes will guide engineering educators in developing tasks that reflect these outcomes and also target them progressively over the four years.

2 Search Method

To conduct the Systematic Literature review (SLR), the process detailed by (Borrego, Foster & Froyd, 2014) has been used. The key steps in the process are listed below with their corresponding application on the present work in subsequent sub sections:

1. Identifying Scope and Research Questions
2. Defining Inclusion Criteria
3. Finding and Cataloguing Sources
4. Critique and Appraisal
5. Synthesis

2.1 Scope and Research Question

The proposed research work answers the research question: "What cognitive and social outcomes of engineering problem-solving are relevant for assessing Collaborative Problem-Solving competency in Engineering Education?" Though Engineering Problem Solving includes four types of problems namely, troubleshooting problems, system-analysis problems and decision-making problems, this article will focus only on design problems.

The research question was dissected into two strands of investigation: collaborative problem-solving(CPS) and engineering problem-solving (EPS).

The purpose of this systematic review is two-pronged: -

1. To identify what is meant by the construct "Collaborative Problem Solving (CPS)" along with the nature of tasks amenable for developing CPS competency
2. To identify the social and cognitive aspects of engineering design problem-solving

The specific details of the two SLRs are discussed subsequently as CPS-Review for collaborative problem solving and EPS-Review for engineering problem solving respectively.

Defining Inclusion Criteria

The inclusion criteria for the two SLRs are listed in Table 1 and the rationale for these decisions is explained subsequently.

Table 1: Inclusion Criteria

Criteria	CPS-Review	EPS-Review
Publication type	Phase 1: Journal Phase 2: all outlets	All outlets
Paper type	Research and literature review	Research and literature review
Publication Date	January 2009 to December 2019	All time
Search String	Phase 1: "Collaborative Problem-Solving"	Phase 1: Engineering design Outcomes OR competency OR competencies -school –teacher

	Phase 2: "Collaborative Problem-Solving" AND assessment (appears in the title)	Phase 2: Spine OR progression OR continuum OR spiral AND "engineering design" (appears in the title)
Language	English	English
Database	Google Scholar	Google Scholar

2.2 Finding and Cataloguing Sources

Google Scholar was used as the search database. Table 2 lists the search criteria and the results obtained from the search results for two searches. The relevance of the articles was considered by referring to the title and abstract.

Table 2: Search results

Criteria	CPS-Review	EPS-Review
Search results	233	177
Relevant after first reading	60	36
Rejected	129	131
References not found	44	10

For CPS-Review, the articles were searched in two phases. During phase 1, the focus was on the different perspectives from which CPS has been studied. The results listed 169 journal articles. The authors did not include all outlets of publication as they intended to explore the landscape of CPS and arrive at an acceptable definition of CPS for further study. During phase 2, the focus was on the assessment of CPS competencies. Restricting the outlets to journals was counter-productive as only 13 articles were found. Hence this restriction was removed. Eliminating duplicate articles from the two searches, a total of 233 articles satisfied the inclusion criteria.

For EPS-Review, the focus of phase 1 was to understand what competencies are desired of engineering students who undergo design experiences. The search yielded 177 articles, of which 27 were relevant. During phase 2, the focus was to understand how the "upward movement" in engineering design competencies was achieved across the four years of undergraduate engineering education. Hence, the search included commonly used terms like spine, spiral, continuum or progression which appeared together with the phrase "engineering design". The search yielded 33 articles, of which 09 articles were relevant. To summarise, from phase 1 and phase 2, a total of 36 articles are related to the development of EPS competencies through design problems.

It was a challenge to download, catalogue, read, filters these articles. Citavi 6.0 and Zotero 5.0.81 reference management tools were used.

2.3 Critique andAppraisal

The search results of 233 and 177 articles for CPS and EPS reviews, respectively, were subjected to the exclusion criteria identified and listed below. Though a few criteria were identified a-priori while others emerged during the first phase of reading.

CPS-Review: Exclusion Criteria

1. The domain is non-engineering education (medical, child psychology, biotechnology, community participation in government policies, industry-projects, teacher training)
2. Lack of Theoretical frameworks of CPS
3. Context of work is school-level education

4. Order of the words collaboration, problem and solving appeared in the title, but the context was not Collaborative problem-solving,
5. The articles were not available on google scholar.
6. Collaborative problem-solving was used as a proxy for collaboration, collaboration strategy and collaborative learning.
7. Context of work was to assess antecedents of CPS like assess creativity, innovation and teamwork.

In all, as of January 2020, applying the above criteria on 233 articles, 60 articles were accepted for further reading under CPS-Review.

EPS-Review: Exclusion Criteria

1. Lack of systematic measurement of design outcomes
2. The focus of the articles was on teacher outcomes.

In all, as of January 2020, applying the above criteria on 177 articles, 36 articles were accepted for further reading under EPS-Review.

The subsequent reading and analysis of the selected articles (60 for CPS and 36 for EPS) concentrated on the focal elements as listed in Table 3.

Table 3: Focal elements for analysis

CPS-Review: Themes	**EPS-Review:** Themes
1. Targeted Cognitive outcomes and social outcomes	1. Targeted Cognitive outcomes and social outcomes
2. Theories on CPS	
3. Task design	

3 Results and Synthesis

This work focuses on answering "What cognitive and social outcomes of engineering problem-solving are relevant for assessing Collaborative Problem-Solving competency in Engineering Education?" In this section, literature has been synthesised for both CPS and EPS for the elements of analysis listed in Table 3 of section 2.

a. Summary of relevant themes on CPS

Restricting to the research question, two relevant themes that are included for discussion on CPS: studies that discuss CPS competencies and studies that describe task design for developing CPS competencies.

i. Studies on CPS

The two recent studies on for CPS competency are the Assessment and Teaching of 21st Century Skills (ATC21S)(Griffin and Care, 2015), a joint effort led by Cisco, Intel, and Microsoft; and the Programme for International Student Assessment (PISA) (He, von Davier, Greiff, Steinhauer & Borysewicz, 2017), a 60-nation assessment administered by the Organization for Economic Cooperation and Development (OECD). These studies have articulated in detail the social and cognitive dimensions for collaborative problem-solving. Table 4 lists the focal competencies for these two frameworks.

The PISA 2015 framework defines CPS as follows:

"Collaborative problem-solving competency is the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution".

Table 5 shows the Matrix of collaborative problem-solving competencies from the PISA program only. The indicators of CPS for ATC21S is available at (Griffin and Care, 2015). The CPS competency can be evidenced from the content and quality of the social exchanges (1, 2 and 3) that transpire during the different phases of problem-solving (A, B and C). Each cell in the table brings to fore what students should be communicating during a specific problem-solving period.

The problem-solving tasks for both programs were domain knowledge-independent and followed a generic problem-solving process. This observation brings us to ponder over how the matrix of collaborative problem-solving competencies for domain-knowledge intensive problem-solving tasks that are collaboratively solved using domain-specific problem-solving processes would look like!

Table 4 Theoretical frameworks for CPS

Framework	Cognitive aspects/Problem-Solving process	Social/Collaborative dimensions	Count
PISA CPS framework (He, von Davier, Greiff, Steinhauer, & Borysewicz, 2017)	1. Exploring and understanding 2. Representing and formulating 3. Planning and executing 4. Monitoring and reflecting	1. Establishing and maintaining a shared understanding 2. Taking appropriate action to solve the problem 3. Establishing and maintaining team organisation	07
ATC21S (Care, Scoular, & Griffin, 2016)	1. Task regulation (Resource management, collect elements of information, Systematicity, Tolerance of ambiguity/tension, organisation (problem analysis), Setting goals 2. Knowledge building (Knowledge acquisition, Relationships (representation and formulation), Rules, hypothesis, Solution	1. Participation (Action, interaction task completion), 2. Perspective-taking (adaptive responsiveness, audience awareness) 3. Social regulation (Negotiation, Negotiation, Self-evaluation, Transactive Memory, Responsibility, initiative)	04

Table 5 Matrix of collaborative problem-solving skills for PISA 2015

Collaboration => Problem-solving	(1) Establishing and maintaining a shared understanding	(2) Taking appropriate action to solve the problem	(3) Establishing and maintaining team organisation
(A) Exploring and understanding	Discovering the perspectives and abilities of team members	Discovering the type of collaborative interaction to solve the problem, along with goals	Understanding roles in solving the problem
(B) Representing and formulating	Building a shared representation and negotiating the meaning of the problem (common ground)	Identifying and describing tasks to be completed	Describe roles and team organisation (communication protocol/rules of engagement)
(C) Planning and executing	Communicating with team members about the actions to be/being performed	Enacting plans	Following rules of engagement, (e.g. prompting other team members to perform their tasks)

(D) Monitoring and reflecting	Monitoring and repairing the shared understanding	Monitoring results of actions and evaluating success in solving the problem	Monitoring, providing feedback and adapting the team organisation and roles

To summarise, the two relevant themes that frequently occur in articles related to CPS are mode of communication and design of tasks that lead to the development of these competencies. In table 6, the overall count of articles for these two themes is listed.

Table 6 Thematic count of studies in CPS

Theme	Observation	Count
1. Mode of communication	Most studies on CPS use digital platforms for communication. It appears that the term CPS is synonymous with Technology-enabled learning. Since the emphasis of these studies is on standardising assessments, the coherence between CPS and TEL environments is explainable.	37
2. Task/assessment Design	One of the precedents to the development of CPS competency is task design, as it is during the execution of the task that collaboration is evidenced. The theory of Evidence-based Design (Oliveri, Lawless, & Mislevy, 2019) provides us with a set of guidelines for the same and is outlined in section 3.1.2. The different types of tasks and their characteristics are discussed in section 3.1.3 and 3.1.4.	02

ii. Deconstructing task design

Task design influences collaboration during the process of problem-solving. To seed the need for collaboration, literature discusses how resources can be selectively shared within the team so that the need for information sharing is introduced by design. The two task designs that provide some insights on resource sharing are: -

1. Symmetric task design: The symmetric design means that the same information and resources are assigned to the two students in the same group to facilitate collaborative activities between them.
2. Asymmetric Task design: The asymmetric design means that different information and resources are assigned to the students in the same group to facilitate collaborative activities between them. Example- Jigsaw-type script or hidden-profile task design The task for ATC21S assessment was asymmetric (Scoular, Care & Hesse, 2017).

While the focus of previous studies is on work distribution, another study (OECD, 2013) describes the nature of tasks which can be solved collaboratively like Consensus building and negotiation tasks.
Consensus building tasks elicit views, arguments and reasoning of different members to decide on an issue. The goals of individual members are aligned to the goal of the task. Negotiation also elicits the above-stated behaviours but group members have different amounts of information and different personal goals. Through negotiation, the goal is the achieve a mutual win-win situation which satisfies overall group goals. (Shaw & Child, 2017). Thus, task-design is an important predictor

iii. Characteristics of Collaborative Tasks

This section summarises the characteristics of collaborative tasks in Table 7. The nature of the task is an important determinant of the degree of collaboration and is a common point of discussion in both the studies.

Table 7 Characteristics of collaborative tasks

Reference	Considerations for creating collaborative tasks
Hall (2014)	Communication – faculty questioning, Peer-Feedback, Off-task and on-task communication Structure- Accountability, control and structure of the task, interaction script, and roles of teacher and student, Group composition- group size, grouping strategy and, Grounding
(Shaw & Child, 2017)	Nature of tasks: Complex tasks and ill-structured Communication: Instil discussion and negotiation for Multiple possible solutions Ill-structured: means/operators are not obvious Non-superfluous use of technology Team formation: Group-formation for positive dynamics, Task must lead to a difference of opinion, assessment must lead to motivation

iv. Evidence-based Design (ECD): The theory of task design

Though characteristics of collaborative tasks are an important frame of discussion for CPS competency, they go no further than basic descriptions. To operationalise these characteristics, what the authors need is a theory of task design that offers systematic steps to deliberate upon, recognise, document, capture and make explicit the expected behaviours that may be associated with different kinds of tasks. One such theory is the Evidence Centred Design (ECD) as discussed in (Mislevy, Almond & Lukas, 2003). The ECD model has five layers:

1. Domain Analysis
2. Domain Modelling
3. Conceptual Assessment Framework
4. Assessment Implementation
5. Assessment Delivery

An application of ECD for developing CPS is seen in (Oliveri et al., 2019), in which CPS was decomposed into specific constructs like the profile of the test taker, focal knowledge and skills, work product, rubrics, task features, usage of technology, among other relevant points necessary to be included in the assessment of CPS.

So far, the authors have discussed the cognitive and social competencies expected from CPS competency. They now proceed to summarise the cognitive and social competencies that are expected from engineering problem-solving.

b. Cognitive and Social aspects of Engineering Problem-Solving through Design Problems

This section identifies the design competencies and categories them as social and cognitive. The final set of 36 articles either focus on developing design competencies via stand-alone courses (course-level focus) or across a program (program-level focus) as listed in Table 7.

The program-level interventions are referred to as a Spine, continuum or progression. These interventions detail how engineering design competencies can be developed by including second and third-year design courses, in addition to first-year and capstone projects. They view design competencies (as listed in Table 8) as a ramp aligned to which the outcomes of the course are articulated leading to the progressive attainment of competencies. Finally, the last set of articles mostly adopted survey research to understand the industry's perspective on the overall competencies for design education.

Table 8: Social and cognitive aspects of Engineering problem solving

Reference	Point of focus	Design competencies	
		Social dimension	Cognitive dimension
(Mavinkurve & Murthy, 2015)	**course-level focus** Electronics Circuits course at Second year		Structure open Problem, Multiple Representation, Information Gathering, Divergent Thinking, Convergent Thinking
(Johnston, Caswell, Douglas, & Eggermont, 2004)	**course-level focus** first-year engineering design and communications course	Teamwork	Product or Process design, Written communication, Visual communication. Each of the above competencies is detailed.
(D. C. Davis, Crain, Calkins, Gentili, & Trevisan, 1997, p. 3), (D. Davis, Beyerlein, & Davis, 2006)	**Overall competencies** Identify competencies required for the effective performance of engineering design and four different levels of achievement within eight categories of design competencies.	Teamwork, Communicator, Collaborator and Leader	Gathering information, Problem definition, Idea Generation, Evaluation and Decision making, Implementation, Communication, Process Improvement **Four Levels of achievement for the competencies:** Basic level, application of knowledge, acritical analysis and extension of knowledge. **Types of observable outcomes:** Knowledge, process skills and products
(Robinson, Sparrow, Clegg, & Birdi, 2005, p. 139)	**overall competencies** Identify a future competency profile for design engineers	Personal attributes	Project management, Cognitive strategies, Cognitive abilities, Technical ability, communication

Table 9 Engineering design competencies developed by program-level interventions

Reference	Outcomes
Professional Spine at The Polytechnic School (TPS) undergraduate engineering program within the Ira A. Fulton Schools of Engineering (FSE) at Arizona State University (ASU).	how outcomes of engineering design are achieved through different categories of projects: Task projects, use-inspired projects, Discipline projects and integrated projects (Graaff & Kolmos, 2003) (Schaefer, Coates, & Eckert, 2019, p. 28)
The Transferable Integrated Design Engineering Education (TIDEE) project	The Transferable Integrated Design Engineering Education project has developed design definitions and assessments for four-year study for the design process, teamwork and design communication (D. C. Davis & Trevisan, 2000).
Engineering Design and Practice Sequence at the Queen's University in Canada	design process methods and tools, problem analysis, creativity, economics and entrepreneurship, engineering communications, professionalism, and ethics. (Frank, Strong, & Sellens, 2018).

The purpose of this systematic review is two-pronged: -

1. To identify what is meant by the construct "Collaborative Problem Solving (CPS)" along with the nature of tasks amenable for developing CPS competency
2. To identify the social and cognitive aspects of engineering design problem-solving

From this brief review, the authors can identify and summarise the differences between the existing studies of CPS and EPS:-

1. Existing CPS frameworks i.e. PISA (Graesser, et al., 2018; OECD, 2013), and ATC21S (Griffin, 2017) are applicable for informal educational settings. Descriptions for developing CPS competency in engineering education do not exist.
2. Both PISA and ATC21S frameworks are modelled after generic problem-solving processes. Engineering professionals solve different types of problems (Design problems, decision-making problems, troubleshooting, systems-analysis and each of these calls for different cognitive processes) (Jonassen, Strobel & Lee, 2006; Jonassen, 2017; Jonassen, 2000). Thus, the cognitive processes in the existing frameworks are not applicable for Engineering Problem-solving.
3. The PISA and ATC21S CPS studies use digital devices as a platform for communication between human-participants (15-year-olds) or use computer agents as a proxy for a human-participant. However, this may be unrealistic in educational environments where collaboration is largely via verbal discourse and/or face-to-face interactions (Graesser, et al.,2018; OECD, 2013). Both PISA and ATC21S focus on computer-based standardised assessments, thus making their frameworks infeasible for formative or summative assessments as conducted in a traditional engineering classroom.
4. Though the development of collaboration and teamwork competencies is the focus of all studies listed in Table 7 and Table 8, little has been said about how to design tasks for engendering collaboration during problem-solving in engineering education.

4 Implications

Keeping these gaps in mind, If collaborative problem-solving experiences are to be included in the engineering curriculum, we, as engineering educators need a reference to rely on. This reference for designing collaborative engineering-problems solving experiences must consider the following: -

1. The task is executed using human-to-human interaction via in-person collaboration.
2. Scripts for facilitating communication between team members during task execution.
3. How to design collaborative tasks concerning enabling communication, structure and group composition (Hall, 2014, p. 58) for solving engineering problems?

The authors intend to develop a reference framework for collaborative engineering-problem solving competency and close this review with a set of open question:-

1. What is the appropriate Learning Design Framework for developing Collaborative Problem-Solving competency in undergraduate engineering education?
2. What types of engineering problems are suitable for developing Collaborative Problem-Solving competency in engineering education at first-year engineering education?
3. What elements should be included in the curriculum/course for developing collaborative problem-solving competency at first-year engineering education?
4. Which support structures should be in place to assist and support engineering educators in developing Collaborative Problem-Solving competency?

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